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PRACTICAL OIL GEOLOGY

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THE APPLICATION OF GEOLOGY TO OIL FIELD PROBLEMS

BY

DORSEY HAGER

PETROLEUM GEOLOGIST AND ENGINEER

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To the

PRACTICAL OIL MAN OF AMERICA, WITH THE HOPE THAT THIS BOOK WILL BRING HIM TO A BETTER UNDERSTANDING OF THE RELATION OF THE GEOLOGIST TO THE PETROLEUM INDUSTRY

PREFACE TO SECOND EDITION

In making a revision of the first edition the author wishes especially to thank Messrs. Johnson and Huntley of Pittsburgh, and Fred Pack on the United States Geological Survey, for their published criticisms of the first edition of "Practical Oil Geology."

He also wishes to thank his many friends and fellow geologists and engineers, especially Mowry Bates and J. W. Lewis of Tulsa, for their suggestions. The industry is so extensive and the work of the geologist is so broad that the writer feels he has but touched on the many uses of geology in oil-field practice, but he hopes the book will prove useful. Certainly it has already more than fulfilled the writer's expectations for which he is deeply appreciative to the reading public.

DORSEY HAGER.

TULSA, OKLA.
November, 1916.

PREFACE TO FIRST EDITION

In the preparation of this book the author aimed to furnish the oil man with a clear, concise, and practical work on the occurrence of oil, and its geology. There are several works on petroleum but none of them is in handbook form. Three of the works are by English authors who give the practice of the East Indian and the Russian oil fields rather than that of America. However the elements of oil-field geology are the same the world over, though the best chances for study are afforded by developments in America. It seemed more than fitting, therefore, that American oil men should have a book treating more particularly of American methods. As the author has gained his experience in these fields it necessarily follows that he gives the American viewpoint, which will perhaps be a just basis for criticism by those who have had a world-wide experience. The author has, however, drawn the data for this book from European as well as American sources and hopes thus somewhat to overcome a natural bias.

The material in this book is derived from the following sources:

(1) The standard text books on general geology such as those by Geikie, Le Conte, Chamberlin and Salisbury, and Kemp.

(2) The bulletins of the U. S. Geological Survey, the technical papers of the U. S. Bureau of Mines and the bulletins of the California, Oklahoma, Illinois, Louisiana, Pennsylvania and Ohio geological surveys.

(3) The articles appearing in the numerous technical journals on mining and on oil, especially papers by Lakes, Clapp, Gordon Sur, Lee Hager, Breger, Arnold, Garfias, Dumble and others.

(4) The following English books: "Petroleum Mining" by A. Beeby Thompson, "Petroleum and Its Sources" by Sir Boverton Redwood, and "Oil Finding" by E. H. Cunningham Craig.

(5) The catalogues of several oil-well supply companies.

The author is also greatly indebted to his good friends among the operators and drillers for many valuable suggestions, and for their assistance in helping him to obtain facts.

Thanks are also given to Messrs. M. J. Munn, J. H. Jenkins, Fohs and Gardner, R. A. Conkling, E. D. Bloesch, Frank Buttram, E. Thomas, Valerius, McNutt and Hughes, and A. T. Patrick for their kindness in affording suggestions and additions to make the work more complete.

Special recognition is due to H. Foster Bain, and to Leon Pepperberg for their criticisms and suggestions, and to F. J. Basedow of Adelaide, Australia, for his assistance in correcting manuscript.

As is the case in all sciences, there is much valuable material which it is difficult to trace and to credit to the originators. The author has made free use of this knowledge, for the facts it presents are among the most valuable we possess.

DORSEY HAGER.

TULSA, OKLA.
April, 1915.

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FOREWORD

Oil Geology—Applied Common Sense

There is at present a rather vague idea in the minds of many men as to just what constitutes an oil geologist. Some people associate him with the "crooked stick" or "peach tree twig" men, others think he uses some hocus-pocus, and as yet comparatively few of the operators see the geologist as a clean-cut, clear-thinking engineer, who is just as much an expert in his line as is the driller or railroad surveyor.

The geologist simply uses engineering methods in arriving at results. Engineering instruments such as transits, levels, barometers, alidades and plane tables are employed, all of which require a mind trained in mathematics for their accurate use. The pick of the geologist, the test-tube and the chloroform bottle are also his working tools. Added to the above instruments, in fact of primary importance, is a mind trained in the reading of surface forms (topography), a knowledge of the ages of formations and their means of identification (stratigraphy), a knowledge of the various folded structures that are important as oil reservoirs, and above all, the ability to recognize such folds in the field.

By studying rock exposure at the surface, by using drill hole records, either of water or oil tests, by readings in mines, etc., the geologist arrives at his conclusions. Of course where all exposures are covered up, and no well records exist, the geologist is "up a stump," and can only say, "I do not know."

The geologist knows from the history of proven oil fields that the surface folding is *generally* an index to underground conditions. Enough holes have been drilled, enough well logs have been plotted to prove this very important point, and it is upon

this fact that the science of oil geology is based. Recognition of the fact that underground folding is reflected at the surface and that such surface folding can generally be seen meant the beginning of a new era for the oil man.

The work of the oil geologist really simplifies itself into the problem of finding folds. When he has found this folding, then he has a basis upon which to work. The following points must be emphasized: First, That all folds do not carry oil; second, a geologist cannot tell whether a fold will carry oil, unless wells are already drilled upon it. A geologist does know, however, that the majority of folds, within certain defined limits, do carry oil, and he can reason from this that the chances are in favor of a well-defined fold being productive, if it occurs within certain boundaries.

In the last few years sand conditions were found to play an important part in oil pools, though not as important as folding. Also many of the largest wells in the world are on faults and not connected in any way with folding.

The work of the geologist does not end with outlining prospective oil lands. His province extends into the field of drilling and of actual oil-field development. To limit geology to prospective territory alone is a great loss, for as one will find from the following pages, there is a wide and varied application of geology to the needs of the oil men in nearly every phase of oil-field work.

PRACTICAL OIL GEOLOGY

CHAPTER I

PETROLEUM—ITS ORIGIN AND ACCUMULATION

Much has been written about the conditions under which oil is found in nature (the structure favorable for the accumulation of petroleum, the age of the formations in which oil occurs, and the technology of drilling, producing, and marketing petroleum), but as yet little positive knowledge regarding the origin of oil has appeared in print although the subject has been discussed very fully from a theoretical viewpoint by many geologists, chemists and engineers. Some of the many theories are discussed below.

CLASSIFICATION OF THEORIES

Theories pertaining to the origin of petroleum may be classified under three main divisions as follows:

(A) Inorganic theories; (B) Organic theories; and (C) Combinations of Inorganic and Organic theories.

Inorganic Theories.—By inorganic is meant any chemical reactions that take place without the aid of living organisms. There are three principal inorganic theories: (1) The carbide theory; (2) the limestone, gypsum, and hot water theory; and (3) the volcanic theory.

1. The *carbide theory* is based upon the fact that in the chemical laboratory carbides of calcium, iron, and several other elements give hydrocarbon products when in contact with water. It is assumed that great quantities of calcium, aluminum, iron and other similar carbides exist deep underground and that the action

of hot water upon these carbides forms liquid and gaseous hydrocarbon compounds that rise upward through fissures and other vents in the earth and collect in the sedimentary beds above. This theory has been strongly supported by some able chemists but it is not advocated by many geologists.

2. The *limestone, gypsum, and hot water theory* is advocated by some writers. According to this theory the action of heated water upon limestone ($CaCO_3$) and gypsum ($CaSO_4$), which in nature are closely associated, give as products the constituents of petroleum. The exact chemical processes have not been fully explained, but it is certain that limestone, gypsum and water contain all the necessary elements for the production of petroleum. Under certain conditions of heat and pressure, it is not impossible that oil may be formed as thus postulated.

3. The *volcanic theory* is based upon the fact that gases given off from some volcanoes carry small percentages of hydrocarbons. These gases are supposedly of deep-seated origin, and carry the products of chemical reactions that occur in the earth. It is assumed that the gases are condensed before reaching the surface by coming in contact with cooler formations near the surface and thus form petroleum. As a laboratory theory the volcanic idea is plausible but it by no means explains most of the occurrences of oil as seen by the field geologist.

Organic Theories.—By organic is meant any chemical process that takes place by assistance of living organisms such as bacteria, decomposing vegetation, or animal matter. Some scientists assert that oil is of animal origin, others that it comes from vegetable matter. There have been numerous discussions as to which is the more likely source. A compromise view asserts that petroleum may come from either source alone, or from a combination of the two. It has been claimed that oils having an asphaltic base are derived from animal matter and that oils with a paraffine base are derived from vegetable matter. Again it is boldly stated that all oils are derived from the same material but that the differences are due to capillary division, differences in the heat and the pressure to which the oil has been subjected, to migration, etc.

There are three organic theories as follows: (1) Animal theories; (2) vegetal theories; and (3) combinations of animal and vegetal theories.

In discussing the following theories the source of the material is alone considered. The subject of the derivation of petroleum from organic matter is treated in another place.

1. ANIMAL THEORIES.—One theory explains that oil is derived from the decomposition of the bodies of marine animals such as fish, oysters, scallops, mollusks, and corals. Some bays and coasts literally teem with marine life at present, and it is assumed that in past ages marine life was just as plentiful, as is evidenced by the great quantities of fossils that are found today. The death of such animals and their subsequent burial in the marine sediments gave material sufficient for the formation of oil.

According to another theory, microscopic organisms called foraminifera, which are today found in great quantities in some places along sea coasts, furnished the material for oil. These small organisms were certainly existent in great quantities in past ages. The microscope shows that beds many hundreds of feet thick are in large part formed of these organisms.

2. VEGETAL THEORIES.—The vegetable theories may be classified under the following heads: (*a*) The sea-weed theory; (*b*) the land-plant theory; (*c*) the diatom theory; and (*d*) the coal theory.

(*a*) The *sea-weed theory* also has received much support. The great kelp beds that line some sea coasts, notably the Pacific Ocean and the Sargossa sea lend strength to this theory. Certainly there is material enough along the coasts to produce a tremendous quantity of oil if properly distilled. Supposing that in the past ages as large quantities of material existed, and were buried in sediments, one has a basis for a strong theory.

(*b*) The *land-plant theory* is based upon the occurrence of great quantities of plants found in land-locked embayments, in swamps, and in low marshes and lake beds. It has been clearly established that coal is formed from plants that grew in great swamps, and it is assumed that similar beds of material under different conditions of heat and pressure gave rise to petroleum instead of to

coal. Certainly plants have all the constituents necessary to form petroleum so that such a theory is not at all unreasonable.

(c) The *diatom theory*, especially advocated by California geologists, is based upon the study of the microscopic plants that are plentiful in many parts of the seas and oceans. Many carbonaceous shales, of great age geologically, contain large quantities of these minute organisms. The presence of petroleum in these diatomaceous shales is so general that many geologists believe the oil originated in the shales. It of course could only come from the microscopic organisms.

(d) The *coal theory* is based upon the fact that lignitic and bituminous coals when distilled in the laboratory yield hydrocarbons similar to those in petroleum. It is thought that similar results are obtained in nature by distilling great masses of coal under proper conditions of heat and of pressure. The presence of coal in many oil fields lends support to this view but like all other theories nothing definite has been established.

COMBINATION OF ANIMAL AND VEGETAL THEORIES.—In some cases one finds the remains of animal and vegetable material in the same bed or stratum. It is very likely where such has been the case that petroleum has been derived from both sources. This view at least reconciles the animal and the vegetable theories, and in no way conflicts with known facts.

Formation of Oil from Organic Material.—The formation of petroleum from either animal or vegetable matter is considered to be as follows:

1. The organic matter is first laid down in clays and sands which have been deposited under water along sea coasts, in swamps, bays, or in lakes.
2. Other beds of material are deposited upon those carrying the organic matter, until a thick covering is formed.
3. The water and the overlying sediments protect the organic matter from rapid destruction by oxidation, and especially where the water is salt, it acts as a pickling brine.
4. In time the pressure of the overlying beds, and the action of heat, which is supposedly generated by the pressure of the over-

lying sediments or by the action of plutonic masses of rock which have been intruded into the sediments, causes a distillation of the organic matter to form petroleum products which are later accumulated into so-called "pools" or fields of oil.

Combination of Organic and Inorganic Theories.—Several theories combining the organic and the inorganic ideas have been offered by scientific men. The principal idea of all these theories is that gases from deep-lying igneous masses pass upward through fissures or vents in the earth's surface, and coming in contact with sediments containing organic matter form hydrocarbon products. There is little positive evidence for such theories except the presence of volcanic intrusions in a few oil fields.

So far as known the organic theories seem the most reasonable and by far the most popular with scientific men.

THE ACCUMULATION OF PETROLEUM INTO COMMERCIAL DEPOSITS

The origin of oil is one problem, its accumulation into economic deposits an entirely different one. More is known about the accumulation of oil than about its origin. The following facts are important to bear in mind as in them one finds the key to many other valuable points of applied geology as related to petroleum.

1. Commercial oil and gas deposits occur in the higher parts of folds or wrinkles of the earth's surface called anticlines, domes, monoclines, etc.

2. Water is always found in the same stratum as the oil but in the lower part of the fold.

3. All commercial deposits so far have occurred in sedimentary or water-laid deposits such as sands, sandstones, conglomerates, shales, and limestones.

4. All oil and gas deposits, so far as known, are capped or covered by practically impervious beds of shale, sandstone, or limestone; also such deposits are underlaid by impervious beds.

The discussion of these points is given under the following

headings: (1) The anticlinal theory; (2) water and compression in accumulation; (3) capillarity; (4) reservoirs for petroleum; and (5) impervious beds capping and underlying the oil and gas deposits.

The Anticlinal Theory.—Anticline is the name given to the type of fold that is arched as shown in Fig. 1. Further reference is made to this type of fold in Chapter III. As the anticline is the most common form of fold found in the oil fields the theory of oil accumulations in folds was given the name anticlinal theory, although several other types of folds also act as oil reservoirs.

Originally the sedimentary strata were laid down along sea coasts, in swamps, lakes, etc., as flat or horizontal beds. Suppose a large *flat* bed of sand, sandstone, conglomerate, shale, or limestone, carrying oil, gas, and water throughout it, to lie buried

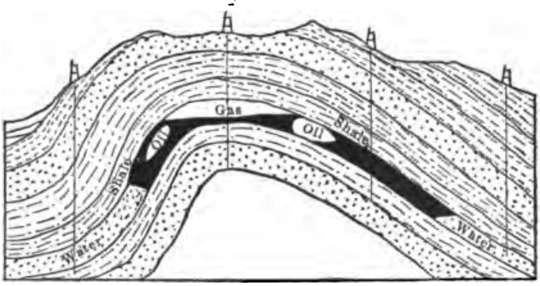


FIG. 1.—Illustration of ideal anticlinal conditions.[1]

under a mass of sediments which are impervious or nearly so; suppose also that this stratum is underlaid by impervious beds. Conditions such as assumed above are common along many sea coasts, in bays, and in gulf regions. In such a *flat* stratum it is found that the gas and oil will rest upon the top of the water due to the differences in specific gravity, gas and oil being lighter than water. In drilling through such a flat stratum the drill will encounter first a layer of gas, then a layer of oil and last a layer of water. However, in such flat strata oil will not be found in paying quantities. To obtain commercial production another condition is essential. There must be a sufficient quantity of oil and gas to pay for its extraction, and such accumulations are found

[1] For symbols used in this book, see Fig. 53, p. 89.

where the flat strata have been thrown into arches or folds like that shown in Fig. 1. As will be noticed in studying Fig. 1, the same stratified or layer-like relations of the gas, oil and water occur as they would in perfectly horizontal beds. At the top of the arch or anticline is gas, below the gas is oil, and at the base of the fold is the water. This is the theoretical condition and is closely approximated in nature. Under certain conditions, however, oil and gas both occur at the top of the arch, and under most conditions there is more or less gas in the oil on the flanks or sides of the structure. The above practically covers the anticlinal theory.

Water and Compression in Oil Accumulations.—In discussing the anticlinal theory one notices that the water was not assumed to be under pressure, but that the oil merely floated upon the top of the water due to differences in specific gravities, much the same as a cork floats upon water. The water occupies the lower parts of the folds because of its tendency to seek its level, a well-recognized truism. Normally under such conditions water occurs in the basins or depressions called synclines, the opposite of anticlines.

Suppose, however, that there are several parallel anticlines or several domes on one anticline (see Fig. 42, Chapter V). The lower arches are under the hydraulic pressure of the oil and the water in the higher arches. In such a case water will occupy the lower anticlines wherever the hydraulic pressure is great enough to drive the oil higher on the slope. Note that the lowest anticline carries no oil. The oil at the top of the structure is not under pressure to any appreciable extent. In the above theory the water is not static or stationary, but is meteoric or rain water, which enters the outcropping sands, and works its way downward into the oil stratum. Also the movement of the water may be due to the rising or falling of the whole land mass. Thus a rising region would result in lowering the water level, and a sinking region would result in raising the water level.

Where faults or where unconformities occur (see Chapters II, III and IV), water by driving oil from the lower sands will force it to enter strata above. Such traveling of oil is called migration

which, however, is not dependent alone upon water pressures. Other factors such as compression discussed below, and capillarity discussed under specific gravity, also assist in migration of the oil from one formation to another. The part that compression plays in oil accumulation would seem to merit more careful attention than has heretofore been accorded the subject. Many shales are saturated with petroleum. If these shales were under sufficiently great pressure the oil would be forced from them. Tremendous pressures are set up by earth folding. Such being the case it is not at all unlikely that the shales in the tops and at the bottoms of the folds may be so compressed that part of their petroleum content would be squeezed out of the shale body. If porous sands or sandstones are above or below the shale, the oil would be forced to migrate into the porous beds. Sand and sandstones are generally more porous than shales and they form better reservoirs than do the shales.

One of the important features of accumulation is the porosity of the beds at the top of the fold. If the beds at the top of the fold are not porous, due either to their being hard compact shales or sandstones little or no accumulation will take place.

CAPILLARITY (After WASHBURNE)

"Extract from Washburne Letter"

"The only matter which I consider as practically proven by my study of the geophysics of petroleum is the control of capillarity upon the distribution of gas, oil, and water within the rocks. Since water has about 50 per cent. higher surface tension than oil, it tends to be drawn into the finest capillaries with half again as much force as that drawing oil into the fine openings. Every slight movement of the various fluids in the rocks tends to move water from sandstone into shale with greater ease than the reverse tendency from shale into sandstone. Likewise, it tends to move gas from shale into sandstone with greater ease than from sandstone into shale. The net result of this tendency, which has operated continuously since the formation of the strata, is to cause the concentration of gas and oil into coarse spaces of rocks, that is, in fissures or sandstone layers in shale, in conglomeratic or other coarse layers in sandstone, etc., leaving the water within the shale. I believe that

this exchange of gas and water between sandstone layers and shale is one of the causes of the apparent dryness of the deep sands of the Appalachian and Mid-continent oil fields. These sands were originally full of water, but in the course of geologic time this water has been exchanged for nitrogen, methane, and carbon-dioxid of the adjacent shales through the operation of capillary forces."

Reservoirs for Petroleum.—As shown above, the higher parts of folds act as great collecting reservoirs for oil. A study of the strata making up such reservoirs will prove of value. The best reservoirs for oil are coarse sands, conglomerates, and porous dolomitic limestones. (See Chapter III for definitions.) Sandstones and shales often carry oil, but they are not the most favorable for reservoirs, as in most sandstones the cementing material binding the sand grains together fills the pores so that the rock can hold only a small quantity of fluid. Shales also have very fine pores and hold only small quantities of oil, except where the shales have been broken into fragments due to intense crushing as is the case with some of the California shales, especially the silicified Monterey shales at Santa Maria.

The percentage of voids in the various kinds of strata varies considerably. Sands may contain from 15 to 25 per cent. voids; sandstones, 5 to 15 per cent. voids; conglomerates may contain as high as 30 per cent. voids; shales, from 2 to 10 per cent., and some dolomitic limestones are reported to contain as high as 35 per cent. voids. The factors above are so variable that one must not take the material in one field to be a criterion or measure of material in other fields. The following discussions on the quantity of oil in the sands, saturation, and drainage areas are all interesting and pertinent to the above discussion on voids.

Quantity of Oil in Sands.—Many people think of lakes of oil lying underground. Such is not the case, by any means. It is entirely unnecessary to call such a theory into use to explain the oil reservoirs. The small voids in the sands afford plenty of space in which oil may accumulate. Some sands contain 20 per cent. voids. If these voids were full of oil, each 100 cu. ft. of sand would contain 20 cu. ft. of oil. A bed 100 ft. thick and covering an acre

of land would then contain the following number of barrels of oil (42 gallons per barrel—7.5 gallons per cu. ft.):

$$\frac{43{,}560 \times 7.5 \times 20}{42} = 155{,}535 \text{ barrels.}$$

Saturation of Oil Sands.—By oil saturation is meant the percentage of oil present by volume in a cubic foot of oil sand. If the voids are 20 per cent., and the sand is filled with petroleum, then the saturation is 20 per cent.[1] However, this method is only a rough approximation, as the amount of oil that a formation holds depends not only upon the porosity but upon the temperatures of the earth, the hydrostatic and the rock pressures. Only when all these factors are known can one obtain an accurate idea of the saturation.

The U. S. Government in its estimates takes 10 per cent. as the saturation. Other estimates allow 1 gallon of oil to each cubic foot of sand (13.3 per cent.), or approximately 1000 barrels per acre-foot. By 10 per cent. saturation is not, however, meant that 10 per cent. of the oil is recoverable. The amount of recoverable oil may only be 50 per cent. of the saturation or it may be as high as 75 per cent. varying with the porosity of the sand, gas pressure, etc. This will be discussed in Chapter VII.

As one can readily appreciate, it is entirely unnecessary to assume lakes to account for the oil below the ground. In some places where the sands are 200 to 300 ft. thick enormous quantities of petroleum are found; in others where the beds are but 10 ft. thick a correspondingly less quantity of oil is found, though this holds true only under certain conditions.

A sand 100 ft. thick fully saturated with oil will produce more oil than one only 10 ft. thick, provided, of course, the size of sand grain and per cent. of saturation are the same, and the gas pressure and dips are constant in both cases. Some thin sands have been very rich producers where coarse grained, producing for a time much larger quantities of oil than thicker beds which were finer grained.

[1] Some scientists call the complete saturation 100%. If but 10% of the voids of the sand were filled the saturation would be 50%.

Porous beds under heavy gas pressures give up their oil very rapidly. A thin bed of sand or limestone which is of coarse texture may then be expected to have a short life compared with thick beds of finer grained material.

The longevity of a well does not determine its productivity, as one well may produce in one month as much oil as others could produce in a lifetime of 15 or 20 years. The great gushers like the Lucas gusher of Spindle Top, Texas, and the Lakeview gusher of California are examples of great productivity. Such wells produced phenomenally for comparatively short periods of time, but soon exhausted themselves.

Drainage Areas.—It has been explained above how oil accumulates and some idea was given as to the quantities in oil strata. In conclusion it is well to touch on the size of the areas from which the oil collects. Drainage area is rather a misnomer as oil does not generally travel downward, but is displaced by water and thus rests upon it. However, the term expresses the same idea as drainage and will be used here to mean that area from which the oil has collected.

Naturally the size of folds varies greatly. Such being the case it follows that the larger the fold, the more oil it should hold, other conditions being equal. The measurement of a fold is not a difficult matter once the basins or depressions are determined. If an anticline is 25 miles long and 10 miles wide, the drainage area is not 25 × 10, or 250 square miles, but will be greater, depending upon the shape of the fold. A fold shaped like that in Fig. 10*a* would not cover as large an area as the fold in 10*b* or in 10*c* (all shown in Chapter III), if the folds were flattened out. A few folds measured by the writer had relative areas of 300, 80, 5, and ⅛ square miles. The large folds give large acreages of available oil land, while the smallest fold would not pay to prospect. It must not be thought that all of the area carries oil. The proportion of oil land in average oil-field drainage areas varies from 1 to 20 per cent. of the total drainage area; however, 5 per cent. would be a large proportion for most oil fields. The areas given above on a 5 per cent. basis would

furnish available acreages of 9600, 2560, 128 and 4 acres respectively. One cannot, however, figure on such an average for the true areas were approximately 5000, 500 and 100 acres respectively. The smaller area was not tested. From these few notes one can appreciate that each field is a problem by itself.

Impervious Beds, Capping and Underlying the Oil Strata.—Oil strata are overlaid or capped, and underlaid by strata practically impervious to oil. These beds may consist of compact shales, hard, closely cemented sandstones, and compact limestones. In all cases the overlying strata must be tight enough to effectually seal in the oil. Where the strata have been eroded leaving exposed sands, the more volatile oils will escape unless asphaltic or paraffine deposits coat the faces of the strata, and act as seals to keep in the remaining oil.

However, as explained under "Effects of Migration," there are conditions where oil may work its way upward through the overlying beds. Also were it not for the compact, overlying beds, water would work its way downward from the surface of the earth and flood the oil strata.

It is just as essential to have a compact underlying bed of material to retain the oil as it is to have a capping. If it were not for such beds the oil would gradually escape downward from the stratum in which it originally occurred. It seems highly probable that such has been the case in some instances. However, water in the lower beds would stop migration, for petroleum will not escape through a rock saturated with water. This applies whether or not the water stratum is above or below the oil stratum. In such saturated rocks the water is held by friction and capillary attraction to the small grains of sediment and the oil has not sufficient pressure to overcome these factors. If for any reason the rocks below lose their water the oil will under some conditions travel downward.

DYNAMIC HEAT GENERATED BY INTENSE FOLDING AND ITS EFFECT ON OIL FIELDS

A theory advanced by David White seems to be applicable in the oil-fields of the Appalachian and Mid-Continent regions.

Briefly stated, the theory is that as one approaches the lines or centers of intense folding the heat generated by the intense folding has been sufficient to volatilize the hydrocarbons in the oil and change them to a more stable gaseous form.

Metamorphism has affected the coals to the extent that the closer the coal is found to the centers of lines of uplift the more anthracitic the coal becomes, *i.e.*, contains more fixed carbon and less volatile water.

This is particularly the case in the Appalachian fields and holds without any question in the southeastern Oklahoma and Arkansas gas fields.

Vast quantities of gas are formed with but small traces of oil. The theory is certainly entitled to serious consideration, and in Oklahoma and Arkansas it has formed an excellent working guide to petroleum geologists.

CHAPTER II

PETROLEUM—PHYSICAL AND CHEMICAL PROPERTIES

DIFFERENCES IN SPECIFIC GRAVITY OF VARIOUS OILS

Specific Gravity.—The specific gravity of any fluid is the relation the fluid bears by weight to the same volume of water. Water has a specific gravity of 1. As petroleum is lighter than water, its specific gravity is expressed by decimals less than unity. Gravity is also expressed in degrees Baumé, a method employed by a French chemist to measure the comparative weight of fluids. The greater the degrees Baumé the lighter the fluid. The relation between the two methods is shown and explained in Table I.

The instruments used are a hydrometer and a standard thermometer. The hydrometer, which is a glass column marked with graduations from 10 to 100, was invented by Antoine Baumé, a French chemist, and the scale on the instrument has always borne his name. The hydrometer when placed in a jar or a bottle of oil sinks to the point on the scale which indicates the gravity in degrees Baumé. The basis of temperature for testing oil is 60° F. and for oil at a greater or less temperature, variations must be calculated. Hydrometers are usually provided with a special scale for figuring temperature variations. The specific gravity is found by dividing 140 by 130 plus the Baumé degrees, for example: if the hydrometer registers 30°, this added to 130 equals 160, which divided into 140 shows specific gravity 0.875°.

Following is a table showing Baumé degrees, specific gravity, and weight per gallon of oil.

TABLE I.—SPECIFIC GRAVITY OF CRUDE OIL AND METHOD OF FINDING IT

Degrees Baumé	Degrees specific gravity	Weight per gallon, pounds	Degrees Baumé	Degrees specific gravity	Weight per gallon, pounds	Degrees Baumé	Degrees specific gravity	Weight per gallon, pounds
10	1.0000	8.33	32	0.8641	7.20	54	0.7608	6.34
11	.9929	8.27	33	.8588	7.15	55	.7567	6.30
12	.9859	8.21	34	.8536	7.11	56	.7526	6.27
13	.9790	8.16	35	.8484	7.07	57	.7486	6.24
14	.9722	8.10	36	.8433	7.03	58	.7446	6.20
15	.9655	8.04	37	.8383	6.98	59	.7407	6.17
16	.9589	7.99	38	.8333	6.94	60	.7368	6.14
17	.9523	7.93	39	.8284	6.90	61	.7329	6.11
18	.9459	7.88	40	.8235	6.86	62	.7290	6.07
19	.9395	7.83	41	.8187	6.82	63	.7253	6.04
20	.9333	7.78	42	.8139	6.78	64	.7216	6.01
21	.9271	7.72	43	.8092	6.74	65	.7179	5.98
22	.9210	7.67	44	.8045	6.70	66	.7142	5.95
23	.9150	7.62	45	.8000	6.66	67	.7106	5.92
24	.9090	7.57	46	.7954	6.63	68	.7070	5.89
25	.9032	7.53	47	.7909	6.59	69	.7035	5.86
26	.8974	7.48	48	.7865	6.55	70	.7000	5.83
27	.8917	7.43	49	.7821	6.52	75	.6829	5.69
28	.8860	7.38	50	.7777	6.48	80	.6666	5.55
29	.8805	7.34	51	.7734	6.44	85	.6511	5.42
30	.8750	7.29	52	.7692	6.41	90	.6363	5.30
31	.8695	7.24	53	.7650	6.37	95	.6222	5.18

To account for the differences in specific gravity of petroleum a number of theories have been presented, as shown below. It is especially important to note the economic side of the question as classified under that head.

EFFECTS OF MIGRATION.—Oil is not generally indigenous to the formation in which it is found, but has migrated from other formations. The migration, or travel, of petroleum from one formation to another undoubtedly affects its specific gravity.

Petroleum is a mixture of hydrocarbons, each having different

specific gravities. If petroleum occurs in a sand, portions of it may work upward or downward through the capping above or the bottom formation underlying the sand. If the cappings or bottoms are very fine grained, only a very small proportion of the hydrocarbons will escape. If shale overlies the sand the lighter part of the hydrocarbons will work its way through the shale to the strata above. The heavy constituents will be left in the sand below, some lighter constituents will be found in the shale, and still lighter constituents in the formations above. If the migration is downward, the oils below will be lighter than those above.

A very thick oil will not penetrate fine-grained clay nor shale, so there is a limit to the amount of petroleum that will escape from the original formation.

Where there are faults or breaks in the formations, allowing the escape of hydrocarbons from deep-lying carbonaceous formations to overlying strata, the lighter constituents may escape from the lower beds and be found above. Water ascending along these fault planes may carry the petroleum with it. Necessarily the petroleum that is mixed with water will be heavier than the original petroleum.

Economic Aspect of Specific Gravity.—As it is known that petroleum in strata of different ages varies, it is of course advisable to know the quality of the oil desired and bore for that stratum. For that reason, if no other, it is often important to know the ages of the formations through which the drill is to penetrate. It is generally true that the high-gravity oils occur in formations that are much younger than those containing the low[1]-gravity oils, although there are exceptions to this rule.

The position of a well on the fold is most important as regards the gravity of the oil to be encountered. In a closed structure such as that in Fig. 1, the lightest oil will occur near the gas line and the heavier oil near the water line, for petroleum is not

[1] On the Baumé scale the gravity decreases with the number of degrees. High gravities would be smaller numbers than low gravities (see Table 1, p. 13).

a homogeneous fluid but a mixture of a number of hydrocarbons which separate in a vessel according to their specific gravities.

Where, however, there is an open structure like that in Fig. 4, Chapter II, the oil near the outcrop will be heavy, due to the escape of the volatile constituents; the oil a little further down the dip will be lighter, and then heavier oil will be encountered near the water line.

Where faulting exposes the beds or allows the escape of oil along the fault plane, heavy oil may be expected in proximity to the fault.

CHEMICAL COMPOSITION OF PETROLEUM[1]

Natural gas, petroleum, bitumen, and asphaltum are all essentially compounds of carbon and hydrogen, or, more precisely, mixtures of such compounds in bewildering variety. They contain, moreover, many impurities—sulphur compounds, oxidized and nitrogenous substances, etc.—whose exact nature is not always clearly defined. The proximate analysis of a petroleum or bitumen consists in separating its components from one another, and in their identification as compounds of definite constitution.

All of the hydrocarbons fall primarily into a number of regular series, to each of which a generalized formula may be assigned, in accordance with the following scheme:

1. C_nH_{2n+2}	6. C_nH_{2n-8}
2. C_nH_{2n}	7. C_nH_{2n-10}
3. C_nH_{2n-2}	8. C_nH_{2n-12}
4. C_nH_{2n-4}	– ....
5. C_nH_{2n-6}	18. C_nH_{2n-32}

Members of the first eight series have been discovered in petroleum. These expressions, however, have only a preliminary value, although they are often used in the classification of petroleum. Each one represents a group of series—homologous, isomeric, or polymeric, as the case may be—and for precise work these must be taken separately. The first formula, for example, represents what are known as the paraffine hydrocarbons, which begin with

[1] After Clark, Data of Geo. Chemistry.

marsh gas or methane, CH_4, and range at least as high as the compound $C_{35}H_{72}$. Even these are again subdivided into a number of isomeric series—the primary, secondary, and tertiary paraffines—which, with equal-percentage composition, differ in physical properties, by virtue of differences of atomic arrangement within the molecules. Each member of the series differs from the preceding member by the addition to the group CH_2, and also by the physical characteristics of greater condensation. Methane, CH_4, for example, is gaseous; the middle members of the series are liquids, with regularly increasing boiling points; the higher members are solids, like ordinary paraffine. These hydrocarbons are especially characteristic of the Pennsylvania petroleum, from which the following members of the series have been separated.

To the list in Table II, the isomeric secondary paraffines, isobutane, isopentane, isohexane, and isooctane must be added, and even then the list is probably not complete. For instance, the solid paraffines $C_{27}H_{56}$ and $C_{30}H_{62}$ have been found in petroleum.

Natural gas consists almost entirely of paraffines, mainly of methane, with quite subordinate impurities. In six samples from West Virginia, analyzed by C. D. Howard, the total paraffines varied between 94.13 and 95.73 per cent.; methane, from 79.95 to 86.48 per cent. and ethane, from 7.65 to 15.09. The following analyses from other sources may be cited more in detail. (See Table III.)

The analyses of Pennsylvania gases by S. P. Sadtler gave somewhat different results. In gas from four different wells he found the following: CH_4, 60.27 to 89.65 per cent.; C_2H_6, 4.39 to 18.39; and H_2, 4.79 to 22.50. The high figures for hydrogen are unusual and suggest a resemblance to coal gas. In all cases, however, methane is the preponderating constituent, the characteristic hydrocarbon of natural gas. In the natural gas of Point Abino, Canada, F. C. Phillips found 96.57 per cent. of paraffines and 0.74 of H_2S.

Hydrocarbons of the form C_nH_{2n} are, as constituents of petroleum, of equal importance to the paraffines. These again fall into several independent series, which vary in physical properties and in their chemical relations, but are identical in percentage

TABLE II.—PARAFFINES FROM PENNSYLVANIA PETROLEUM

Name	Formula	Melting point	Boiling point
1. Gaseous:		° C.	° C.
Methane	CH_4	−186	−164
Ethane	C_2H_6	−172.1	− 84.1
Propane	C_3H_8	....	− 37
Butane	C_4H_{10}	....	+ 1
2. Liquid:			
Pentane	C_5H_{12}	....	37
Hexane	C_6H_{14}	....	69
Heptane	C_7H_{16}	....	98
Octane	C_8H_{18}	....	125
Nonane	C_9H_{20}	− 51	150
Decane	$C_{10}H_{22}$	− 31	173
Endecane	$C_{11}H_{24}$	− 26	195
Dodecane	$C_{12}H_{26}$	− 12	214
Tridecane	$C_{13}H_{28}$	....	....
Tetradecane	$C_{14}H_{30}$	+ 4	252
Pentadecane	$C_{15}H_{32}$	....	....
Hexadecane	$C_{16}H_{34}$	18	....
3. Solid:			
Octodecane	$C_{18}H_{38}$	....	....
Eicosane	$C_{20}H_{42}$	37	....
Tricosane	$C_{23}H_{48}$	48	....
Tetracosane	$C_{24}H_{50}$	50–51	....
Pentacosane	$C_{25}H_{52}$	53–54	....
Hexacosane	$C_{26}H_{54}$	55–56	....
Octocosane	$C_{28}H_{58}$	60	....
Nonocosane	$C_{29}H_{60}$	62–63	....
Hentriacontane	$C_{31}H_{64}$	66	....
Dotriacontane	$C_{32}H_{66}$	67–68	....
Tetratriacontane	$C_{34}H_{70}$	71–72	....
Pentatriacontane[1]	$C_{35}H_{72}$	76	....

[1] For a description of these higher, solid paraffines, see C. F. Mabery, Am. Chem. Jour., vol. 33, p. 251, 1905. The literature of these substances is so voluminous that I cannot attempt to give exhaustive references. C. Hell and C. Hägele (Ber· Deutsch. chem. Gesell., vol. 22, p. 504, 1889) have described an artificial hydrocarbon, $C_{60}H_{122}$.

TABLE III.—ANALYSES OF NATURAL GAS

	A	B	C	D	E	F
CH_4	....	....	....	....	93.36	97.63
Paraffines[1]	96.36	98.90	87.27	93.56	....	....
C_2H_4, etc	....	....	....	....	0.28	0.22
CO	....	....	....	....	0.53	1.32
CO_2	3.64	0.40	0.41	0.14	0.25	0.22
H_2	none	none	none	none	1.76	none
N_2	none	.70	12.32	6.30	3.28	0.60
H_2S	none	none	none	none	0.18	....
O_2	none	none	none	none	0.29	trace
	100.00	100.00	100.00	100.00	99.93	100.00

A. From Creighton, Pennsylvania.

B. From Pittsburg, Pennsylvania.

C. From Baden, Pennsylvania.

D. From Vancouver, British Columbia. Analyses A to D by F. C. Phillips, Am. Chem. Jour., vol. 16, p. 406, 1894. Selected from a table of seventeen analyses to show extreme variations.

E. Mean of four gases from Indiana and three from Ohio, analyzed by C. C. Howard for the United States Geological Survey. Cited by W. J. McGee, Eleventh Ann. Rept., U. S. Geol. Survey, pt. 1, p. 592, 1891.

F. From Oswatamie, Kansas. From a table of seven analyses by E. H. S. Bailey, Kansas Univ. Quart., vol. 4, p. 1, 1895. According to H. P. Cady and D. F. McFarland (Trans. Kansas Acad. Sci., vol. 20, p. 80, 1907), the natural gas of Kansas contains helium. It was found in forty-four samples, in amounts from 0.01 to nearly 2 per cent.

composition. One series, the olefines, is parallel to the paraffine series, and the following members of it are said to have been isolated from petroleum.

Table (IV) is probably exact in an empirical sense, but not so constitutionally. Hydrocarbons of the indicated composition have undoubtedly been found, and some of them are certainly olefines. According to C. F. Mabery, however, the true olefines, or "open-chain" series, are present in petroleum at most in very small amounts. In Canadian petroleum Mabery and W. O. Quayle identified hexylene, heptylene, octylene and nonylene.

[1] Largely CH_4, with more or less ethane. CO not found by Phillips.

In other cases, and notably in the Russian petroleums, the compounds C_nH_{2n} are not olefines, but cyclic hydrocarbons of the polymethylene series, which were originally called naphtenes. They were at first supposed to be derivatives of the benzene series, and it is only within recent years that their true constitution has been determined. In Russian oils they are the principal constituents, and according to C. F. Mabery and E. J. Hudson they also predominate in California petroleum.

TABLE IV.—SO-CALLED "OLEFINES" ISOLATED FROM PETROLEUM

Name	Formula	Melting point	Boiling point
1. Gaseous:			
Ethylene	C_2H_4		−103
Propylene	C_3H_6		− 18
Butylene	C_4H_8		− 5
2. Liquid:			
Amylene	C_5H_{10}		+ 35
Hexylene	C_6H_{12}		68
Heptylene	C_7H_{14}		98
Octylene	C_8H_{16}		124
Nonylene	C_9H_{18}		153
Decylene	$C_{10}H_{20}$		172
Undecylene	$C_{11}H_{22}$		195
Duodecylene	$C_{12}H_{24}$		216
Tridecylene	$C_{13}H_{26}$		232.7
Cetene	$C_{16}H_{32}$		275
——	$C_{20}H_{40}$		
3. Solid:			
Cerotene	$C_{27}H_{54}$	65–66	
Melene	$C_{30}H_{60}$	62	

Members of the series from C_7H_{14} to $C_{15}H_{30}$ were isolated from the California material. Mabery and S. Takano also found that Japanese petroleum consisted largely of C_nH_{2n} hydrocarbons. Other similar occurrences are recorded in the treatises of Hofer and Redwood.

The series C_nH_{2n-2} is often called the acetylene series, after its first member, acetylene, C_2H_2. The lower members of this series have not been found in petroleum, but several of its higher members are characteristic of oils from Texas, Louisiana, and Ohio. In oil from the Trenton limestone of Ohio, Mabery and O. H. Palm found hydrocarbons having the composition $C_{19}H_{36}$, $C_{21}H_{40}$, $C_{22}H_{42}$, and $C_{24}H_{46}$. With these compounds were also members of the next series, C_nH_{2n-4}—namely, $C_{23}H_{42}$, $C_{24}H_{44}$, and $C_{25}H_{46}$. In petroleum from Louisiana, C. E. Coates and A. Best found the hydrocarbons $C_{12}H_{22}$ and $C_{14}H_{26}$. These, together with $C_{16}H_{30}$, were also separated by Mabery from Texas oils. These oils are furthermore peculiar in containing free sulphur, which separates in crystalline form.

Table V shows the average chemical composition of a number of petroleums.

Table VI gives the commercial values of the same petroleums.

ANALYSES

TABLE V.—ELEMENTAL ANALYSES[1]

Nos.	Field	Specific gravity at 15° C.	Heating value per gram	Hydrogen	Carbon	Nitrogen	Sulphur	Undetermined
			Calories	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
545	Kern River composite[2] ..	0.9670	10,312	11.27	86.36	0.74	0.89	0.74
535	Coalinga......	.9505	10,400	11.30	86.37	1.14	.60	.59
542	McKittrick...	.9600	10,186	11.41	86.51	.58	.74	.76
543	Midway......	.9580	10,314	11.61	86.58	.74	.82	.25
544	Sunset........	.9705	10,233	11.37	85.64	.84	1.06	1.09

[1] The samples were dried by filtering twice through about 2 cm. of anhydrous sodium sulphate before analysis.

[2] See Table VI.

TABLE VI.—HEATING VALUE OF CALIFORNIA PETROLEUM AND COMMERCIAL PRODUCTS OBTAINED THEREFROM

Lab. No.	Oil fields	Commercial						Summary													
		Specific gravity at 15° C.	Degrees Baumé at 60° F.	Heating value			Weight per gallon	Flash point (open cup)	Burning point (open cup)	Viscosity at 20° C, (Engler scale)	Water	Sulphur	Naphtha (unrefined)	Fuel oil	Gasoline (refined)	Lamp oil (refined)	Lubricants (refined)	Refining losses	Distilling losses	Asphaltum (commercial)
				Per gram	Per pound	Per gallon														
				Cal.	B.t.u.	B.t.u.	Lbs.	°C.	°C.		%	%	%	%	%	%	%	%	%	%
545	Kern River																			
	Average of 40 samples	0.9645	15.16	10,307	18,553	148,980	8.03	108	130	915.6	0.5	0.83	....	99.5	....	6.6	39.2	5.9	0.5	47.3
	Composite sample[2]	.9670	14.78	10,312	18,562	149,610	8.06	102	128	690.0	.5	.89	....	99.5	....	3.0	40.9	5.8	.5	49.3
535	Coalinga																			
	Average of 62 samples	.9498	17.52	10,404	18,727	148,130	7.91	88	110	341.5	.2	.59	....	99.7	....	11.0	43.6	6.8	.7	37.7
	Composite sample[3]	.9505	17.29	10,400	18,720	148,262	7.92	72	103	64.5	.4	.60	....	99.6	....	8.7	39.4	6.1	1.0	44.4
542	McKittrick																			
	Average of 26 samples	.9566	16.37	10,282	18,508	148,276	8.01	87	115	200.0	2.0	.78	....	98.0	....	13.2	41.0	6.6	.8	36.4
	Composite sample[4]	.9600	15.83	10,186	18,335	146,680	8.00	74	109	160.7	1.5	.74	...	98.5	....	14.0	36.5	6.1	1.2	40.7
543	Midway																			
	Average of 29 samples	.9570	16.34	10,341	18,613	148,345	7.97	78	99	518.1	.3	.83	0.1	99.6	0.1	14.4	39.7	6.6	.7	37.8
	Composite sample[5]	.9580	16.14	10,314	18,565	148,149	7.98	61	87	137.9	.5	.82	....	99.5	....	15.3	33.9	5.8	.7	43.8
544	Sunset																			
	Average of 25 samples	.9701	14.37	10,206	18,478	149,302	8.08	89	113	527.2	1.7	1.02	.3	97.9	.3	8.3	37.9	5.8	.7	45.3
	Composite sample[6]	.9705	14.26	10,233	18,419	149,010	8.09	71	101	604.2	.4	1.06	....	99.6	....	10.7	32.5	5.2	.9	50.3

[1] Calculated, Chemical and Metallurgical Handbook, Cremer and Bicknell.

[2] Composed of 30 grams each of laboratory Nos. 126–165.

[3] Composed of 20 grams each of laboratory Nos. 6, 9, 11, 13, 15, 18, 26, 27, 30, 44, 49, 51, 52, 54, 59, 63, 67, 69, 70, 71, 74, 76, 372–410.

[4] Composed of 40 grams each of laboratory Nos. 84–99, 369, 475–482.

[5] Composed of 40 grams each of laboratory Nos. 100–108, 454, 456–474.

[6] Composed of 50 grams each of laboratory Nos. 109–124, 446–453, 367.

TABLE VIa.—AVERAGE ANALYSES SHOWING COMMERCIAL VALUES OF OKLAHOMA OILS

Location	Specific gravity, (at 15° C.)	Degrees Baumé, (60° F.)	Calories per gram	B.t.u. per pound	Viscosity at 20° C. (Engler scale)	Water (per cent.)	Sul-, phur per cent.)
Avant	0.8617	32.49	10,828	19,490	2.3	[1]	0.17
Bald Hill	.8465	35.40	10,905	19,629	2.3	0.1	.17
Bartlesville	.8604	32.71	10,883	19,585	2.3	[1]	.14
Bigheart	.8547	35.58	10,904	19,589	2.3	.0	.16
Checotah	.8610	32.60	10,910	19,638	3.5	[1]	.11
Cleveland	.8388	36.94	10,921	19,658	1.7	.0	.21
Collinsville-Claremore	.8585	33.10	10,846	19,524	2.6	.0	.20
Cushing	.8389	37.00	10,911	19,639	2.0	.0	.27
Flat Rock	.8635	32.14	10,804	19,448	3.0	.0	.26
Glenn Pool	.8445	35.83	10,879	19,582	1.8	.2	.28
Gotebo	.8595	32.89	10,925	19,665	2.9	[1]	.25
Hamilton Switch	.8439	35.92	10,907	19,633	2.0	.0	.18
Henrietta	.8720	30.55	10,761	19,370	3.3	[1]	.35
Hominy Creek	.8585	33.09	10,838	19,508	2.7	.1	.20
Madill	.8504	34.64	10,893	19,608	3.7	.0	.16
Mounds	.8635	32.14	10,826	19,488	3.5	.0	.22
Muskogee	.8304	38.60	11,009	19,817	1.5	.0	.10
Nelagony	.8615	32.51	10,827	19,489	2.4	[1]	.19
Nowata	.8525	34.22	10,920	19,656	1.8	[1]	.14
Okmulgee	.8530	34.13	10,850	19,531	2.6	.1	.20
Oresa	.8665	31.58	10,836	19,506	3.0	.3	.18
Osage City	.8472	35.30	10,879	19,506	2.0	.0	.24
Pawhuska	.8710	30.73	10,807	19,453	6.6	.1	.23
Ponca City	.8144	41.91	10,998	19,797	1.2	.0	.10
Red Fork	.8457	35.57	10,928	19,670	1.9	.0	.24
Salt Creek	.8511	34.52	10,881	19,585	2.6	.0	.17
Sapulpa	.8635	32.14	10,826	19,486	2.7	.0	.25
Schulter	.8600	32.84	10,840	19,513	2.8	.0	.23
Turley	.8772	29.67	10,790	19,422	7.2	.0	.23
Wheeler	.9166	22.76	10,554	18,998	40.2	.6	1.20
Grand average	.8544	33.96	10,870	19,567	3.9	.0	.23

[1] Trace.

TABLE VIb.—ANALYSIS OF OIL FROM WAYNE COUNTY, KENTUCKY, WELLS

Location of well	Depth of well (feet)	Physical properties: Gravity at 60° F.: Specific	Physical properties: Gravity at 60° F.: Baumé	Physical properties: Color	Physical properties: Odor	Distillation by Engler's method: Begins to boil at °C.	By volume: To 150° C.: Cubic centimeters	By volume: To 150° C.: Specific gravity	By volume: 150°–300° C.: Cubic centimeters	By volume: 150°–300° C.: Specific gravity	By volume: Residuum: Cubic centimeters	By volume: Residuum: Specific gravity	By volume: Total: Cubic centimeters.	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.): Crude	Unsaturated hydrocarbons (per cent.): 1500–300° C.
Parnell pool Sunnybrook "sand," Polly Lair farm, P. M. Burwald, Monticello.	692	0.8083	43.2	Light green.	Like Pennsylvania oil.	43	27.0	0.7047	33.0	0.8017	37.3	0.9061	97.3	2.47	0	....	14.8	6.0
Sinking pool, Beaver Creek "sand," Wood Oil Co., Monticello.	600	.8154	41.7	Dark green.	do.	65	22.0	.7273	36.0	.8043	38.6	.9038	96.6	3.73	0.56	....	11.6	2.0
Oil Valley pool, Beaver Creek "sand," Ohio & Kentucky Oil Refining Co., Oil Valley.	690	.8154	41.7	....	do.	50	20.0	.7129	36.0	.7989	39.7	.9121	95.7	3.34	1.78	....	14.8	2.0
Johnson Fork field..........	...	.8408	36.5	Brown.	do.	53	13.5	.7201	32.0	.7980	49.9	.9235	95.4	3.01	2.66	....	31.2	4.0
....	...	.8235	40.0	Dark green.	do.	60	16.5	.7187	32.0	.7934	46.9	.9056	95.4	4.57	0	....	18.8	7.0
Cooper pool, Beaver Creek "sand," B. S. Huffaker farm, Pa. Lubricating Co., Monticello.	...	.8178	41.2	Black..	do.	35	25.0	.7155	29.0	.8062	42.1	.9186	96.1	2.65	.80	....	14.4	14.0
Turkey Rock pool, Slickford district, Jos. Brown & Co., Slickford.	...	.8163	41.5	Dark green.	do.	60	23.0	.7181	36.0	.7947	40.2	.9038	99.2	2.31	.36	....	15.6	14.0
Rocky Branch pool (near Monticello), Grant Roberts farm, Demsey Oil Co., Bradford, Pa., first oil from well.	187	.9021	25.2	Black..	do.	170	....	......	26.0	.8183	73.0	.9259	99.0	5.49	....	Tr.	63.0	3.0
Parmleysville pool (north end), Beaver Creek "sand," James Burnett farm, Ross, Wetzel & Co., Parmleysville.	...	.8348	37.7	Dark green.	do.	76	13.0	.7174	36.0	.7959	47.9	.9115	96.9	5.09	....	Tr.	2.0	5.0

[1] Crisman No. 1. [2] Ingram No. 1 [3] Z. W. Morris No. 4

TABLE VIc.—OILS FROM PENNSYLVANIA AND TEXAS

Location of well	Depth of well (feet)	Physical properties					Distillation by Engler's method							Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.)	
		Gravity at 60° F.		Color	Odor	Begins to distill at °C.	By volume												
							To 150° C.		150°–300° C.		Residuum		Total						
		Specific	Baumé				Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters					Crude	150°–300° C.
PENNSYLVANIA																			
(Not located)	....	0.8861	28.0	....	......	...	.....	.....	12.0	.....	.....	.....	.....	....	..	....	....	....	....
Do	....	.8160	41.6	....	......	...	19.7	.....	44.77	0.792	35.52	......	99.99						
Perry County, Millerstown.	....	.7901	47.2	....	......	...	17.0	0.693	43.0	.765	40.0	......	100.0	....	..	....	....	....	....
Venango County	....	.8822	28.7	Dark brown.	......	...	8.55	.....	42.78	......	48.67	......	100.0	....	..	....	....	....	....
TEXAS																			
Bexar County																			
San Antonio	....	.8800	29.1	Reddish brown.	......	...	4.73	.745	36.90	.8117	58.37	......	100.0	2.02	..	....	....	....	....
Do	....	.9179	22.5	do.	......	...	1.10	.....	27.30	......	71.60	......	100.0	1.52	..	....	....	....	....
Hardin County																			
Sour Lake pool:																			
Township 75, Cannon tract, O. T. Taber, Sour Lake.	1310	.9067	24.4	Dark green.	Sulphur	95	3.0	.....	31.0	.8597	65.9	0.9440	99.9	....	0	0.0	Tr.	31.2	11.0
Taber Oil Co., Sour Lake.	1780	.9272	21.0	Black	do.	185	.....	.....	20.0	.8721	79.4	.9409	99.4	....	0	.40	Tr.	46.0	9.0
Rodger's tract township 81, Taber Oil Co., Sour Lake	....	.9421	18.6	do.	do.	187	.....	.....	19.0	.8761	80.4	.9472	99.4	....	0	.57	Tr.	36.4	9.0
Graham and Gore, Sour Lake.	1745	.9144	23.1	do.	do.	95	1.0	.....	25.0	.8377	72.0	.9377	98.0	....	0	.0	Tr.	31.2	11.0
Sun Co., Beaumont	1020	.9352	19.7	Dark green.	do.	170	.....	.....	23.0	.8750	76.7	.9569	99.7	....	0	.0	....	59.6	11.0

TABLE VI*d*.—ANALYSES OF OILS FROM LANDER FIELD, FREMONT COUNTY, WYO.

Serial No.	Well No.	Depth of well (feet)	Physical properties: Gravity at 60° F., Specific	Physical properties: Gravity at 60° F., Baumé	Physical properties: Color	Distillation by Engler's method: Begins to boil, °C.	By volume: To 150° C., Cubic centimeters	By volume: To 150° C., Specific gravity	By volume: 150°–300° C., Cubic centimeters	By volume: 150°–300° C., Specific gravity	By volume: Residuum, Cubic centimeters	By volume: Residuum, Specific gravity	By volume: Total cubic centimeters	Paraffin (per cent.)	Asphalt (per cent.)	Unsaturated hydrocarbons: Crude (per cent.)	Unsaturated hydrocarbons: 150°–300° C., (per cent.)
Wyo. 3.	3	750	0.9198	22.2	Dark brown	93	2.5	....	22.0	(1)	(1)	(1)	(1)	(1)	(1)	50.4	(1)
Wyo. 4.	2	400	.9126	23.4	do.	120	2.0	....	23.5	0.8041	69.9	0.9543	95.4	0.91	4.02	46.4	4
Wyo. 5.	10	825	.9121	23.5	do.	93	2.0	....	21.0	.8067	75.2	.9589	98.2	1.27	5.69	50.8	4
Wyo. 6.	11[2]	965	.9126	23.4	do.	105	1.5	....	24.0	.8018	73.9	.9605	99.4	.90	11.04	58.0	4
Wyo. 7.	13	697	.9091	24.0	do.	108	2.5	....	23.0	.8047	73.1	.9589	98.6	.62	15.26	50.8	9
Wyo. 8.	Plunkett.	300	.8121	42.4	Green	77	14.0	0.7244	41.0	.7994	41.1	.8755	96.1	5.85	.0	10.4	5

[1] Flask broke during distillation. Water in the oil.

[2] No. 11 here is No. 9 on the map.

A complete analysis of several petroleums are presented below.

ANALYSIS OF SULPHUR MOUNTAIN PETROLEUM COMPANY VENTURA COUNTY, CALIFORNIA

Gravity	17.6° Baumé
Viscosity at 60° F.	81.15 Redwood
Viscosity at 185° F.	2.65 Redwood
Flash point	Below 60° F.
Sulphur	1.46 per cent.
Thermal value	18,551 B.t.u.

Distillation Results

Sample of 200 c.c. distilled in glass with steam.

		Gravity
Below 212° F.	3.1 per cent.	58.0° Baumé
212° to 302°	4.8 per cent.	50.7° Baumé
302° to 392°	8.1 per cent.	41.2° Baumé
392° to 482°	7.4 per cent.	32.4° Baumé
482° to 572°	8.8 per cent.	28.8° Baumé
572° to grade D asphalt	20.0 per cent.	20.5° Baumé
Asphalt	25.0 per cent. grade D	
Water and loss	2.8 per cent.	
	100.0 per cent.	

This corresponds in round figures to the following commercial analysis.

Gasoline	61.0° Baumé	2 per cent.
Distillate	52.0° Baumé	6 per cent.
Kerosene	42.0° Baumé	8 per cent.
Stove oil	34.0° Baumé	6 per cent.
Fuel oil	28.0° Baumé	30 per cent.
Lubricating stock	20.5° Baumé	20 per cent.
Asphalt grade D		25 per cent.
Losses		3 per cent.
		100 per cent.

ANALYSIS OF CUSHING, OKLAHOMA, OIL

The following tests made on Cushing crude oil by the Cosden Refining Company at Tulsa will also give an idea of the character of the Cushing oil.

RESULT OF A TEST RUN ON 30,000 GALLONS OF 40.9° BAUMÉ CUSHING CRUDE, FROM BARTLESVILLE, WHEELER, AND LAYTON SANDS

Crude benzine	36.0
80 per cent. of this if re-run would be finished 60 per cent. gasoline	
Kerosene	20.0
Gas oil	10.0
Wax distillate	21.0
Residuum	9.0
Layton crude with 43.5° Baumé	
Gasoline 60° to 61° gravity	50.0
Water white 40° to 41° gravity	12.5
Residuum or road base	33.5
Loss	4.0

Test of 580 bbl. of Cushing crude 40° Baumé from Bartlesville, Wheeler, and Layton sands

207.54 bbl. crude benzine, or 35.78 per cent.
96.66 bbl. water white distillate, or 16.67 per cent.
177.68 bbl. wax distillate, or 30.64 per cent.
70.37 bbl. residuum, or 13.51 per cent.
19.7 bbl. loss, or 3.4 per cent.

Wheeler crude 41.2° Baumé	
Gasoline 60° to 61° gravity	37.5
Water white 40° to 41° gravity	21.0
Wax distillate	26.0
Tar, or heavy residuum	12.0
Loss	5.5

Records obtained from the Superintendent of the Cosden Refining Company, Tulsa, Oklahoma.

CHAPTER III

STRATIGRAPHY

Stratigraphy is the detailed study of the order of deposition, and the relative ages of the stratified rock that make up the earth's crust.

CLASSES OF ROCKS

All rocks that make up the earth's surface belong to three great classes:

(1) Igneous rocks, or volcanics. (2) Sedimentary rocks, and (3) Metamorphosed igneous and sedimentary rocks.

Igneous rocks are of many different kinds—granites, syenites, basalts, etc.

Sedimentary rocks, such as clays, shale sands, sandstones, limestones and other fragmentals are derived from material broken from the igneous rocks, and from other sedimentary rocks.

Metamorphics,—gneisses, schists, slates, etc., are due to changes in both the igneous and sedimentary rocks.

Any one prospecting for oil, is most interested in sedimentary rocks. These rocks are formed by the breaking down of igneous rocks due to the action of rains, frosts, winds, running water and other agencies. Beds of material are deposited along stream courses, along the sea coasts and lake shores. The principal types of sedimentary formations are classified as follows: Conglomerate; sand; sandstones; clay; shales; and limestones.

Gravel—Conglomerate.—Loose aggregates of rounded or water-worn pebbles are called gravel. When pebbles become cemented together into coherent rocks, they form conglomerates. Silica, calcite, and limonite are the principal cements that bind the particles together.

Gravel and conglomerate of limited extent indicate the former presence of swift streams; if of wide area they suggest the existence of sea beaches and the advance of sea over land.

Sand—Sandstones.—The sediments finer than pebbles and yet of noticeable size, such as beach-sands or river-sands, are classed as sands. They are generally made up of quartz grains. In river sands, the grains are angular—in beach sands, rounded. Where sands are cemented by calcite and limonite, they form sandstones and when by silica they form quartzites.

Clays—Shales.—Clay is made up of very fine-grained particles principally of aluminous materials containing considerable water. Clays are formed in deeper water than sands. Shales are laminated rocks made up from hardened muds, silts or clays, as the result of pressure.

Limestones.—Limestones are formed principally of calcium carbonate resulting from the deposition of calcium salts in lake beds, or the accumulation of corals and the shells of other marine organisms, in coral reefs, or on the ocean floor.

All of the classes of rocks above named are modified to form sub-classes and types without number. For all practical purposes the above definitions are sufficient.

Deposition.—It is an ascertained fact that the sea coasts of the world are either rising or falling very slowly. This being true, it is assumed that the ancient sea coasts were also rising and falling. Indeed, such must have been the case when we find great beds of sea-shells upon high mountain tops. Suppose a sea coast is sinking slowly and as the sedimentary material is deposited it is constantly covered up by the addition of matter above it. In time, layers, hundreds of feet thick, are accumulated. Sometimes such layers or beds contain much organic material in them. Again, the coasts may rise slowly and in time be above water. At the same time, the forces that caused this rising (due, perhaps, to the contraction of the earth which constantly tends to become smaller in diameter) caused a folding or crumpling of the earth's crust.

We thus have reasons both for the accumulations of great thick-

ness of material and for the occurrence of various formations above sea level. The types of structure caused by crumpling and the attendant changes are classified in Chapter IV.

Source of Supply of Material.—In every region there is a certain part from which the materials that form the sedimentary rocks are derived. In most regions, igneous or volcanic rocks form the backbone of the mountain ranges, and it is from these that the materials are derived.

The tendency of every bed is to decrease in thickness away from the source of supply. When the source of supply is known, it is not difficult to predict the thickening and thinning of beds and the occurrence of conglomerates, of sands, and of shales. Conglomerates form near the source of supply, sands farther away, and shales at a still greater distance.

Variations in Beds.—The thickness of beds in some districts may increase or decrease greatly in the distance of a mile or more.

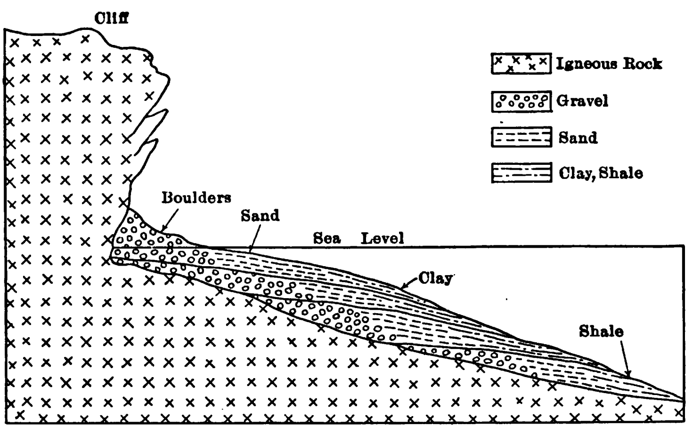


Fig. 2.—Illustrates the formation of sediments along a sea coast.

With some formations, such as boulders and stream deposits, changes may occur in much shorter distances. Shale and sand beds 1500 ft. thick have totally disappeared in a little over

5 miles. A bed may start as a conglomerate, in ½ mile change to a sand, and further on to shale. (See Fig. 2.)

Knowledge of such changes is of great importance in determining reservoirs for oil, and in locating well sites to obtain the most productive wells, as will bé shown later.

Where underground waters percolate through the formations, and carry cementing material, conglomerate, sandstone, and silicified shale result. Where cementing material is absent, loose gravel and soft shales occur. It is in these gravel beds, sands, and shales that oil finds its best resting place.

Conformity—Unconformities.—Where beds are deposited in order without breaks, as in Fig. 2, they are conformable. Beds *B*, *C*, and *D*, in Fig. 3, are also conformable.

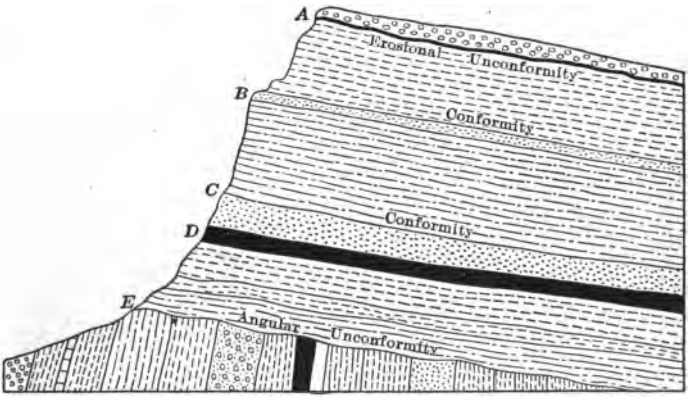


FIG. 3.—Illustrates conformity, erosional and angular unconformity

Where the beds have been pushed above water and exposed to erosion, then have sunk again and other beds formed upon them, one finds an erosional unconformity, as shown at *A*, in Fig. 3.

Where beds have been deposited, then upheaved, and folded, later eroded and have then sunk again, and still later beds deposited on them, a condition similar to that at *E* in Fig. 3 results. This condition is called an angular unconformity.

Fig. 4 illustrates a condition by no means uncommon. The lowest formation is older than the upper and was tilted before the upper bed was deposited on top. Wells at 1, strike sand *A*; at 2, *A* and *B*; at 3 *A*; at 4, *A* and *C*.

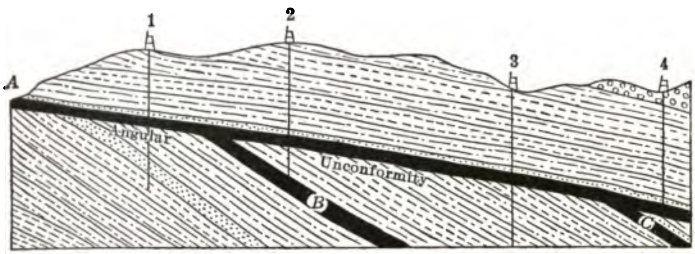


FIG. 4.—Illustrates angular unconformity, its relation to migration of petroleum, also relation of wells on such a structure.

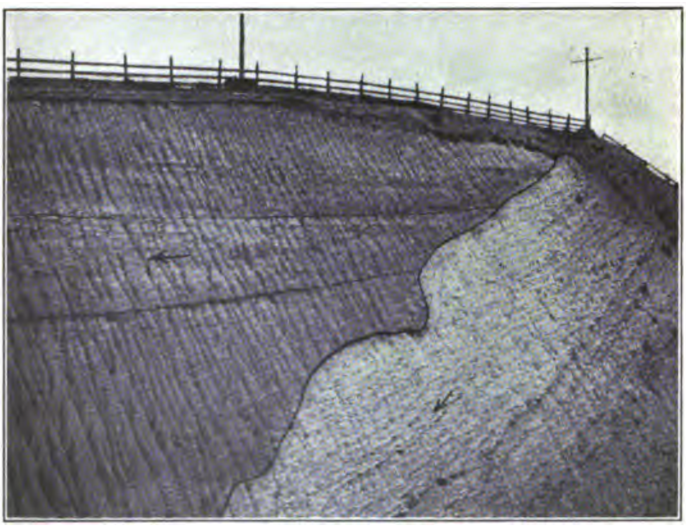


FIG. 5.—Unconformity between tilted Monterey shale and horizontal Pleistocene sand and gravel in California. (Bull. 322, U. S. G. S.)

OVERLAP.—If beds are deposited along shore lines while the Coast is slowly sinking, the first beds, *A*, laid down (see Fig. 6) are covered by material that is in turn covered and hidden by later beds, *B*, *C* and *D*. The higher beds progressively lap over the lower beds. Fig. 6 shows an overlap and also an unconformity between the crystalline rocks and the sedimentaries.

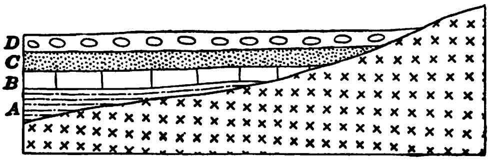


FIG. 6.

RELATIVE AGES OF FORMATION

Order of Superposition.—The relative ages of beds depend primarily upon the order of their deposition. Normally the older beds are beneath the younger. This simple law is the basis for determining the ages of beds. However, folding and faulting may change the position of certain beds but not their age.

Hardness of Formations.—The older the formations, the harder they are, generally. Sand grains when cemented become sandstones, shales become compressed and cemented to form slates. Jointing also becomes more pronounced in the older rocks.

Lithologic Similarity.—Many times attempts have been made to correlate or classify rocks in a region according to their color, texture, or mineral composition. Such means of correlating do not hold good under all conditions, and serious mistakes are sometimes made by correlating certain beds which in reality may be some distance apart. The surest test of working out any structure is to "walkout" the beds, that is, follow one known bed in all its rising and falling. In some places such

procedure cannot be accomplished, in others it is not necessary as the structure can be clearly seen.

A sandstone of Cretaceous age may look exactly like one of Miocene age in color and in texture. Sands of both ages often appear identical. However, in some cases, where marked dissimilarity appears over a district, certain formations may be readily correlated.

If a thick red shale occurs in a region it may extend over several hundred square miles and act as a horizon marker.

Conglomerates, due to terrestrial or near-shore conditions, are not reliable markers as they may die out within 1 or 2 miles.

Some sandstones are very persistent. They mark old beach conditions; and often cover entire counties. Limestones are also very persistent horizon markers.

It is essential to discover the peculiarities of any formation, for where fossil evidence is lacking such peculiarities are often of value in checking up formations within the limited radius of 2 to 3 miles.

Fossils.—The proper correlation of beds is best accomplished by the use of fossils. It has been found that when certain classes of fossils occur in a stratum, the age of the stratum is fixed definitely and its position above or below others is determined. However, fossil evidence must be used very carefully and only by experienced workers.

Fossils, such as oyster shells, scallops, gasteropods and microscopic organisms (foraminifera and diatoms), form the chief basis for stratigraphic classification.

Fossils may be of great value to the geologist and practical man, but it is important, however, to know the fossils that are characteristic of certain horizons.

In some regions beds of known ages carry oil and all others may be ruled out. The ages are determined by the order of superpositions as explained above, and by fossil evidence. Where beds are overturned as in Fig. 7, fossil evidence gives a clue to the true condition. The fossils in *A* are younger than those in *B*. Normally *A* would overlie *B* as at *I*. At *II* the

order is reversed while at *III* the order is normal again. The true order of the beds is then as shown at *I* and *III*. Other evidence, as dips and curvatures, generally bear out such conditions, and in some cases actual folds in miniature show the true condition.

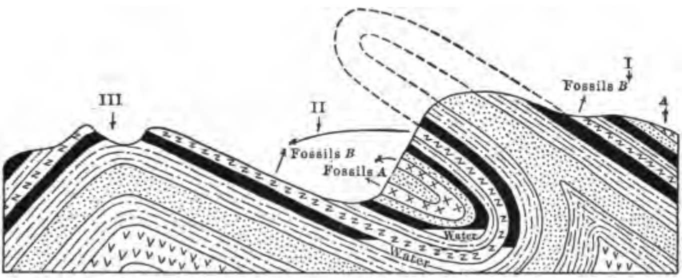


FIG. 7.—Illustrates the use of fossils in correlating formations.

By means of fossils one may often correlate oil-bearing formations many miles apart. Fig. 8 shows the application of fossil evidence. At *I* oil occurs under the beds carrying certain fossils, as oysters and scallops. At *II* the same fossils occur

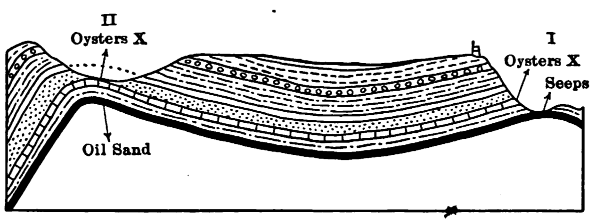


FIG. 8.—Illustrates the use of fossils in correlating formations.

which would lead one to believe that the same oil strata underlie the fossil beds occurring at this point.

Oil operators from Pennsylvania will see certain formations in California, say a sandstone, that looks very much like a bed in Pennsylvania. Immediately the operators will call the bed

the same age, when in reality there is absolutely no connection between the two. The California oil formations are millions of years later than the Pennsylvania oil formations. The lowest California oil is in the topmost Cretaceous, and the highest Pennsylvania formations are in the Carboniferous system. Table VIII shows the difference between the Eastern and Western oil horizons. These differences are worked out by correlating the fossil evidence throughout the United States.

Geologic Column.—A geologic column (see Fig. 9) is often of great assistance. By means of such a column one knows the formations that must be penetrated by the drill, the thickness of each formation, the depth to oil, etc.

These vertical sections enable the contractors and drillers to choose drilling rigs, and to determine the depths, hardness of formations, etc. Such a column is merely a graphic representation of the stratigraphy of a region. One column does not hold good over a very large area, so new sections must be made for different parts of a region to take into account local changes in thickness, character, etc.

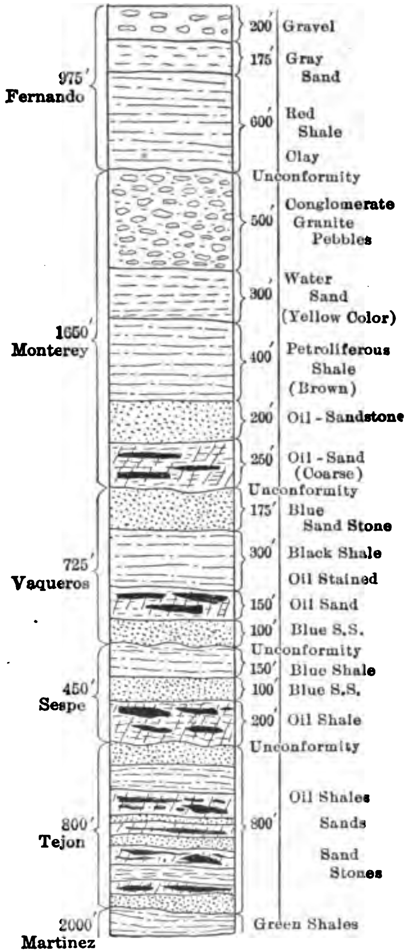


FIG. 9.—Geologic column of California.

Geological Names (After J. F. Kemp).—"In the advance of geological science the standpoints from which the strata forming the earth's crust are regarded necessarily change, and new points of view are established. In the last few years two have become especially prominent, and there are now two sharply contrasted positions from which to obtain a conception of the structure and development of the globe. The first is the physical, the second is the biological.

"For example, we consider the surface of the earth as formed by rocks, differing in one part and another, and these different rocks or groups of rocks are known by different names. The names have no special reference to the animals found in them, but merely indicate that series of related strata form the surface in particular regions.

"On the other hand, the rocks are also regarded as having been formed in historical sequence, and as containing the remains of organisms characteristic of the period of their formation. They illustrate the development of animal and vegetable life, and in this way afford materials for historical-biological study. In the original classification, the biological and historical considerations are all-important.

"But when once the rocks are placed in their true positions in the scale, and are named, these considerations for many purposes no longer concern us. The formations are regarded simply as members in the physical constitution of the outer crust.

"The International Geological Congress held in Berlin in 1885 expressed these different points of view in two parallel and equivalent series of geological terms, which are tabulated below. They are now very generally adopted. For clearness in illustration the equivalent terms employed by Dana are appended.

Biological Terms	Physical Terms	Dana's Terms	Illustrations
Era	Group	Time	Paleozoic
Period	System	Age*	Devonian
Epoch	Series	Period	Hamilton
Age*	Stage	Epoch	Marcellus

"The United States Geological Survey divides as follows: *Era* and *System*, *Period* and *Group*, *Epoch* and *Formation*. In considering the ore deposits of the country, we employ only the physical terms. We understand, of course, the chronological positions of the systems in

*In making reports to the layman the term "Age" is probably the easiest understood.

historical sequence, but it is of small moment in this connection what may be the form of life enclosed in them. The purely physical character of the rocks—whether crystalline or fragmental; whether limestone, sandstone, granite or schists; whether folded, faulted or undisturbed—are the features on which we lay especial stress. In all the periods the same sedimentary rocks are repeated, and in the hand specimens it is almost always impossible to distinguish those of different ages from one another."

DEFINITIONS OF FORMATION AND MEMBER

(After *Snyder*)

"The systems of rocks are divided into smaller groups known as formations. A formation is defined as a mappable unit, that is a layer of rock or group of layers which extends entirely across the area under consideration and has sufficient width of outcrop to be mapped. Formations may consist of single ledges or beds of rock, but commonly are made up of two or more closely related beds.

The separate beds are sometimes called members. Thus, the principal oil sands of the main (Oklahoma) oil and gas field may be considered as members of the Cherokee formation. The formations and members are usually named from the place where they are best developed or where they were first studied. The Pitkin limestone which outcrops east of Muskogee and Ft. Gibson is an example of a formation consisting of only one kind of rock. The Ft. Scott formation, known to the drillers as the Oswego, is usually called the Ft. Scott limestone, but really consists of two limestones separated by a shale. Formations may vary in thickness from a few feet to thousands of feet. Thus the Chattanooga shale in northeastern Oklahoma is not over 50 feet thick while the Arbuckle limestone in the Arbuckle Mountains is over 5,000 feet thick. Formation names are a great convenience since they provide a means of designating certain beds of rock without repeating extended descriptions. They are necessarily used extensively in the description of the geology of any region."

The accompanying geological charts, and tables show the productive oil horizons of the western United States.

TABLE VII.—GEOLOGICAL ERAS AND THEIR SUBDIVISIONS

Cenozoic	Present	
	Pleistocene	
	Pliocene	
	Miocene	
	Oligocene	
	Eocene	
Transition—Aprapahoe and Denver		
Mesozoic	Upper Cretaceous	
	Lower Cretaceous	Comanche or Shastan
	Jurassic	
	Triassic	
Paleozoic	Carboniferous	Permian Pennsylvanian Mississippian
	Devonian	
	Silurian	
	Ordovician	
	Cambrian	
Great unconformity		
Proterozoic	Keweenawan	
	Unconformity	
	Animikean	
	Unconformity	
	Huronian	
Great unconformity		
Archeozoic	Archæan	Great granitoid series intrusive in the main Laurentian
	Complex	Great schist series Mona, Kibchi, Keewatin, Quinneseo.

TABLE VIII.—GEOLOGICAL FORMATIONS OR "SANDS" IN WHICH OIL AND GAS ARE FOUND IN THE UNITED STATES AND CANADA

This chart was prepared with a view of showing the various oil and gas sands with reference to their age and position in the stratified rocks forming the earth's crust. Owing to the fact that some of the oil fields have not been given thorough geological study and also that geologists are not yet certain regarding the age of several of the formations, this chart is of course approximated. Dotted lines indicate points at which uncertainty exists.

Era	Geological system	Geological series or group	Producing formation or sand	Correlation	
CENOZOIC	Quaternary	Recent series	Alluvial deposits	Beaumont, Texas, and Jennings, Louisiana.	
	Tertiary	Pliocene	Tulare formation	Lost Hills, California.	
		Miocene series: Upper Miocene	Jacalitos formation	Coalinga, California.	
			McKittrick formation	McKittrick-Sunset, California.	
			Fernando formation	Santa Clara River & Los Angeles, California.	
		Middle Miocene	Monterey shale	Santa Maria, California. Summerland, California.	
			Puente formation	Los Angeles, California. Salt Lake District; California.	
		Lower Miocene	Vaqueros sandstone	Coalinga, California. McKittrick-Sunset, California. Santa Clara River, California. Parkfield, California.	
MESOZOIC		Eocene series	Sespe formation	Sespe Fields, California. Santa Clara River, California.	
			Tejon	Coalinga, California.	
			Topa Topa	Santa Susana, California Sespe Fields, California.	
	Cretaceous	Upper Cretaceous	Chico formation	Coalinga, California.	
			Mancos shale	Colorado. Lander & Wind River, Wyoming.	
			Dakota sandstone	North Dakota. Alberta, Canada (Gas).	
			Webberville formation	Corsicana, Texas.	
			Aspen formation	Spring Valley, Wyoming.	
			Colorado formation	Big Horn Basin, Wyoming.	
			Wall creek sandstone (Lentil of Benton shale)	Salt Creek, Wyoming.	
			Nacatoch sand	Caddo, Louisiana (Gas).	
			Woodbine sand	Caddo, Louisiana (Oil).	
		Lower Cretaceous	Trinity sand	Medill, Oklahoma.	
	Jurassic	....	Sundance formation	N. E. Wyoming.	
	Triassic	....	Chugwater formation	Wyoming.	

TABLE VIII.—(*Continued*) (OKLAHOMA)

Era	Geological system	Geological series or group	Producing formation or sand	Correlation
PALEOZOIC	Carboniferous	Pennsylvanian	Blackwell	
			Sand	
			Sand	
			Newkirk	Elgin ss. at Cleveland
			Sand	
			Sand	
			Ponca	
			Musselman	
			Sand	
			Sand	
			Layton of Cushing	Peoples of Cleveland
			Wayside	Layton of Cleveland Jones-McEwan
			Big lime	
			Cleveland	
			Peru	
			Oswego lime	Wheeler
			Lower Wheeler	Peters
			Squirrel	Bixler-? Peru
			Skinner	
			Pink lime	
			Red Fork	
			Namira	
			Sand	
			Bartlesville	Glenn
			Sand	
			Tucker	Burgess-Squaw Taneha Meadows
			Sand	
			Dutcher	Lost city, 96th meridian Rhodes, Colbert

TABLE VIII.—(*Continued*) (OKLAHOMA)

Era	Geological system	Geological series or group	Producing formation or sand	Correlation	
		Mississippian	Mounds		
			Sapulpa		
			Boone lime	Main Mississippi lime	
			Sand		
			Pitkin lime		

TABLE VIII.—(*Continued*) (S. E. OKLAHOMA)

PALEOZOIC	Carboniferous	Pennsylvanian	Sand		
			Sand		
			Oswego lime	Calvin sandstone	
			Sond		
			Gas of Morris	Glen-Bartlesville	
			Sand		
			Sand		
			Booch		
			Second Booch		
			Sand		
			Sand	Mounds	
			Morris	Sapulpa	
			Glen of Morris		
			Sand		
			Sand		
		Mississ-ippian	Fields	Muskogee-Boynton Black-deep sand	
			Sand		
			Sand		

TABLE VIII.—GEOLOGICAL FORMATIONS OR "SANDS" IN WHICH OIL AND GAS ARE FOUND IN THE UNITED STATES AND CANADA (*Continued*)

Era	Geological system		Geological series or group	Producing formation or sand	Locality where productive	Approximate depth below Pittsburg coal. Feet
PALEZOIC	Carboniferous		Permian series.			
		Pennsylvanian series	Upper coal measures	Embar formation	Lander, Wyoming.	....
				Goodridge sand	Bluff, Utah.	....
			Middle coal measures.	Connellsville sand	West Virginia.	40
				Morgantown sand	West Virginia.	80
				Macksburg sandstone	S. E. Ohio.	200
			Lower coal measures.	First Cow Run sand	S. W. Penna. & W. Va.	320
				Middle Cow Run sand.	S. W. Penna., W. Va. & S. E. Ohio.	450
				Lower Cow Run sand	S. W. Penna., W. Va. & S. E. Ohio.	600
				Bridgeport sand	Bridgeport, Ill.	....
				700 and 800 ft. Macksburg sands	S. W. Penna., W. Va., S. E. Ohio & Ky.	850 & 925
			Pottsville group.	Salt sands, Gas, sand	S. W. Penna., W. Va., S. E. Ohio & Ky.	950 to 1080
				Cherokee sandstones	Kansas & Oklahoma.	....
				Buchanan sandstone	Casey & Robinson (400 ft.) Ill., and Princeton, Ind.	....
		Mississippian series	Chester group.	Benoist sand	Sandoval, Ill.	....
				Kirkwood sand	Robinson & Bridgeport, Ill. & Oakland City, Ind.	....
			Pocono group.	Keener sandstone	S. E. Ohio & W. Va.	1275
				Big Injun sand, Squaw sand	S. W. Penna., W. Va., S. E. Ohio & Ky.	1340, 1425
				Berea grit	S. W. Penna., W. Va., S. E. Ohio & Ky.	1700
				First, 100 ft. or Gantz sand	W. Penna., W. Va. & S. E. Ohio.	1850
				50 ft. sand	W. Penna. & W. Va.	1885
				Second or 30 ft. sand	W. Penna. & W. Va.	2000

TABLE VIII.—GEOLOGICAL FORMATIONS OR "SANDS" IN WHICH OIL AND GAS ARE FOUND IN THE UNITED STATES AND CANADA (*Continued*)

Era	Geological system	Geological series or group	Producing formation or sand	Locality where productive	Approximate depth below Pittsburg coal. Feet
PALEZOIC	Devonian		Stray or Bowlder sands.	W. Penna. & W. Va.	2050
			Third or Gordon sands.	W. Pa., W. Va. & Ohio.	2130
			Fourth, fifth and sixth sands	S. W. Penna. & W. Va.	2200, 2260 & 2590
			First, second and third Warren sands	N. W. Penna.	2700, 2815 & 2900
			Tiona sand	N. W. Penna.	2950
			Speechley sand	N. W. Penna.	3020
			Cherry Grove sand	N. W. Penna. & W.N.Y.	3150
			Bradford sand	N. W. Penna. & W.N.Y.	3460
			Elk County sands	N. W. Penna. & W.N.Y.	3650
			Hamilton formation	Petrolia & Oil Springs, Ontario.	5330
			Corniferous limestone	N. E. & Central Ohio, W New York & Ontario.	5625
	Silurian	Niagara group.	Oriskany sandstone	New York, So. Ind. & Ont.	5660
			Guelph limestone	Ontario & W. New York.	5700
			Niagara limestone	W. New York, Ontario & Indiana.	5820
			Clinton limestone Clinton sandstone	Cen. Ohio & Welland Co., Ontario.	5985 6025
			Medina red sandstone Medina white sands	W. New York & Welland Co., Ontario.	6085 6200
	Ordovician		Trenton limestone, upper.	N. W. Ohio, Ind. & Ky.	8700
			Trenton limestone, lower	N. W. Ohio, W. New York & Ontario.	9200
	Cambrian		Calciferous and Potsdam sandstone	N. Y., Ga., Ala & Ontario.	....
			Quebec group	Newfoundland. New Brunswick.	9230

STRATIGRAPHICAL DISTRIBUTION OF PETROLEUM PRODUCTION TO 1913

It is interesting to note the ages that produce the oil of America. The table presented below, after Clapp (Petroleum and Natural Gas Resources of Canada, Vol. I) shows which ages have been productive.

Tertiary..........	1,935,763,780 bbls.	California, Gulf Coast; Foreign except Canada.
Upper Cretaceous..	42,548,025 bbls.	Marion Co., Corsicana to Powell, Texas; Wyoming; Colorado.
Pennsylvanian.....	343,843,256 bbls.	Electra and Henrietta, Texas; Oklahoma; Kansas.
Mississippian......	726,815,070 bbls.	Illinois; one-half of the Appalachian field.
Upper Devonian...	540,304,235 bbls.	One-half of the Appalachian field.
Devonian.........	14,099,053 bbls.	Canada.
Ordovician........	318,095,570 bbls.	Lima-Indiana.

NOTE.—In Oklahoma there is some question as to whether or not the Permian is an oil-producing horizon of importance. It is certainly an important gas producing horizon but the petroleum side has not been established definitely. The recent find at Garber, Oklahoma, is apparently Permian, close to the Pennsylvanian contact.

CHAPTER IV

STRUCTURAL GEOLOGY

OIL FIELDS ON FLANKS OF GREAT MOUNTAIN UPLIFTS

One great truth that must be emphasized is the occurrence of oil-fields on the flanks of the great centers or lines of uplifts. Thus all the American oil-fields at least, and most European fields, occur in the folded regions contiguous to centers or lines of disturbance. The centers of these uplifts show the older granitic rocks, and necessarily do not carry oil, but minor folds affecting the sedimentary rocks form favorable conditions for accumulation. The California fields occur both on the east side of the Coast range, and the west side of the Sierras Nevada. Again, the Utah fields, Wyoming fields, and Colorado fields occur on the flanks of the Rocky Mountains. The north Oklahoma and the Kansas fields occur on the west flank of the Ozark uplift, the western Illinois fields be on the east flank of the Ozark uplift.

The LaSalle uplift affects the central Illinois and Indiana oil-fields. The Cincinnati uplift controls part of Indiana, Ohio and Kentucky. The West Virginia and east Pennsylvania fields occur on the West side of the Alleghenies. The southern Oklahoma oil-fields center around the Arbuckle uplift. The Sabine uplift controls the northwestern Louisiana fields, and the Burkburnett uplift in Texas controls the north Texas fields. In Mexico the oil fields occur on the eastern flank of the Mountains.

Nearly every oil field in the world occurs in close relationship to some earth curve or fold. Underground structure is one of the most important features of oil-field geology. So much depends on favorable structure that a careful study of the various types of oil-field structure is necessary. Below is a classification that is sufficient for all practical purposes:

1. Anticlines..
   - Single
   - Compound
     - Symmetrical
     - Asymmetrical
     - Overturned
2. Synclines...
   - Single
   - Compound
     - Symmetrical
     - Asymmetrical
     - Overturned
3. Monoclines... Terraces
4. Combinations of 1, 2 and 3
5. Domes.
   (*a*) Anticlinal
   (*b*) Saline
   (*c*) Volcanic
6. Faulted forms of any of the above.
7. Stratigraphic forms—lenses, fracture planes, etc.

Every fold is part of an earth curve and must be considered as continually changing in dip or slope. The cause of folding is problematic. It is thought to be the result of the contraction of the earth's surface due to internal cooling. In places the crust of the earth is forced by folding into arches, and sags or basins. The results of such folding are structures called anticlines, synclines, domes and monoclines. Breaks or faults may affect all the above forms and make still more complicated structures.

Where masses of igneous rocks force the strata upward, folds very similar to domes are formed. Volcanic necks or plugs may thus lift the formations around them, forming arched structures that are important factors in the accumulation of petroleum. Another form of arching such as the Saline domes of Texas and Louisiana is thought to be due to recrystallization of salt masses. The folds generally decrease with depth. Folding is near-surface phenomenon, as is often noticed the folds become more contracted toward the center and flatten with depth.

1. **Anticlines.**—The distinction between anticlines and domes is at present loosely drawn. In this book anticlines will be differentiated from domes as follows:

An *anticline* is a long, relatively narrow fold with the dips or slopes of its sides inclining away from a line of folding called an axis. Such a fold will eventually disappear due to gradual

flattening or to faulting, merging with other folds, etc. When the fold flattens out, the ends of the fold plunge or dip along the line of the axis resulting in what is designated a plunging anticline. An anticline takes its type name from its cross-section. Folding is not only along a plane vertical or inclined to the horizon, but is also sinuous on the surface. Where folds curve sharply the beds on the inside of the curve are compressed; those on the outside are under tension. This results in localizing the oil at those portions of the fold which are opposite the point of greatest compression.

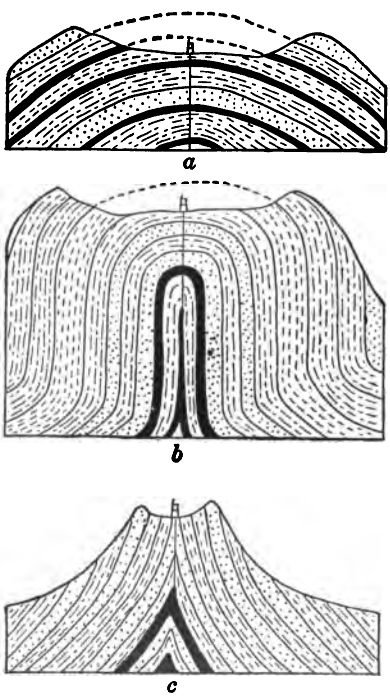


FIG. 10.—Forms of symmetrical anticlines.

The simple anticline has but one high place or apex. If two or more high places form on the long fold such high places are designated anticlinal domes. The low places on the anticlines between such domes are called "saddles." Other names for anticlinal domes and saddles are "structural highs" and "structural lows" respectively. A fuller discussion of anticlinal domes is given later in this work. Two other types of domes are also found which will be discussed later.

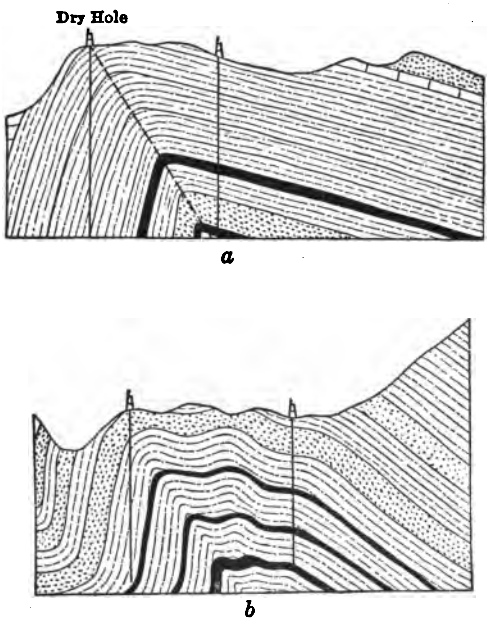
Anticlines are of many forms of types: *Symmetrical anticlines* are those anticlines in which the inclinations or dips on both sides of the axis are equal. (See Fig. 10 *a*, *b*, and *c*.)

Asymmetrical or inclined anticlines occur when one of the limbs or flanks has a greater dip than the other. (See Fig. 11*a*,

11*b* and 12.) Asymmetrical anticlines are the most common type of fold. Folds are overturned when the axes of the folds fall over, as in Fig. 14 also as in Fig. 7 in Chapter III.

Isoclines belong to a peculiar type of symmetrical anticlines. Such folds are not very common but occasionally occur.

Compound anticlines consist of a system of parallel anticlines which often cover a large area. The California and Pennsylvania oil fields clearly illustrate this condition.



Figs. 11*a* and 11*b*.—Types of asymmetrical anticlines.

2. Synclines.—A syncline is a structure the reverse of an anticline, and receives its name because its beds incline toward a common central line.

Synclines are as varied as anticlines, and for every anticline one will nearly always find a similar syncline. Three examples of synclines are shown in Figs. 15, 16 and 17.

FIG. 12.—Inclined fold Temescal Ranch, Ventura County. (After Watts, Calif. Mining Bureau, Bull., 19.)

FIG. 13.—View of South Mountain anticline near Santa Paula, Calif.

When the basins are filled with water, oil may be found on the flanks of synclines. When little or no water occurs in the basin, oil may be found close at the bottom of the depression. (Figs. 15, 16 and 17.)

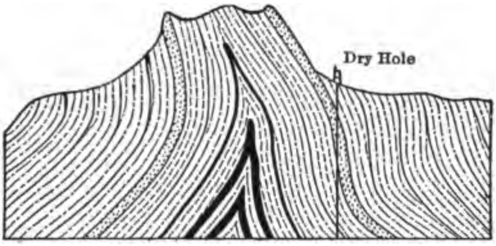


FIG. 14.—Steeple-shaped anticline overturned at top.

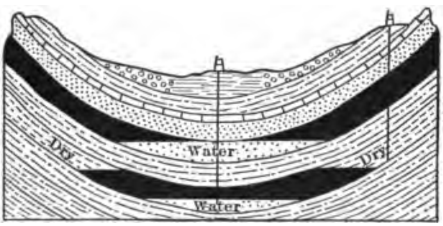


FIG. 15.—Illustrates possibility of finding oil in synclines.

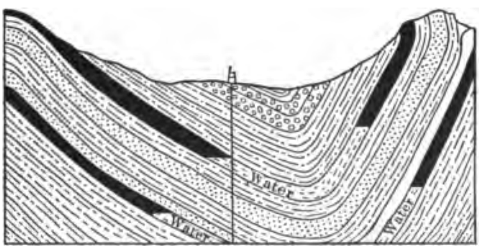


FIG. 16.—Illustrates an asymmetrical syncline.

Deformation.—The amount of arching is called the deformation of the structure. It is measured from the bottom of the syncline to the top of the anticline. (See Fig. 18.)

In California, Wyoming, and other steeply folded areas, deformations of 500 to 5000 ft. are known.

In Oklahoma and Kansas deformations of 10 to 200 ft. are known, but by far the larger proportion of structures show only 40 to 60 ft. deformation. Cushing, the most productive of all

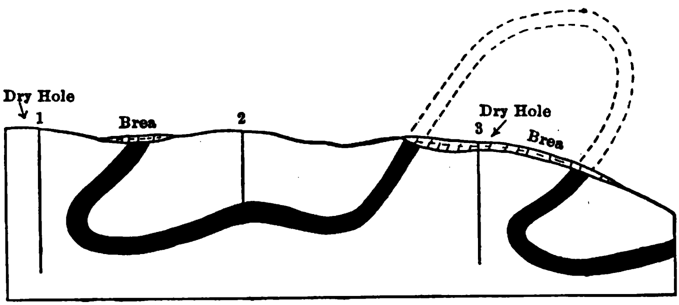


FIG. 17.—Illustrates complex folding. (After U. S. G. S.)

Oklahoma pools, shows 160 ft. from the syncline to the top of the dome. Such low deformations usually occur in distances of half a mile to a mile. An East dip 160 ft. in a distance of 6 miles occurs near Onaga in Pottawatomie County, Kansas.

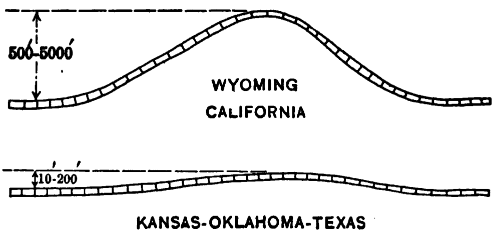


FIG. 18.

3. Monoclines.—A monocline is a structure with one slope or inclination. Its name comes from mono, one, and clino, sloping.

Monoclines are simple structures as shown in Fig. 19. They are often limbs or flanks of giant anticlinal folds or of giant domes, where but one side of the fold is apparent and that dipping in one direction. The northeastern Oklahoma oil-fields are located

on minor folds that occur on a great northwestern dipping monocline.

Normal Dips.—In all regions of uplift the dip of the beds is naturally away from the center or line of the uplift. The great

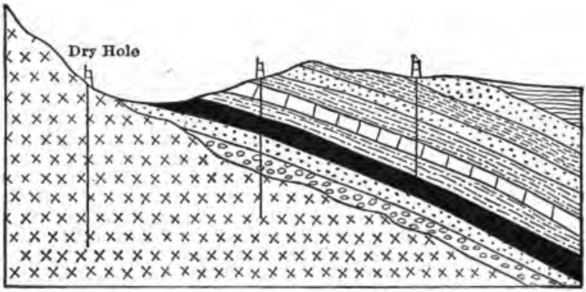


FIG. 19.—Illustrates wells on a monocline.

monocline formed by these dipping beds are broken by minor folds. The dip of the monocline as a whole is called the normal dip of the country, and decreases in intensity from the center of folding outward. In Kansas and northern Oklahoma the normal westward dips vary from 15 to 30 ft. per mile. In central

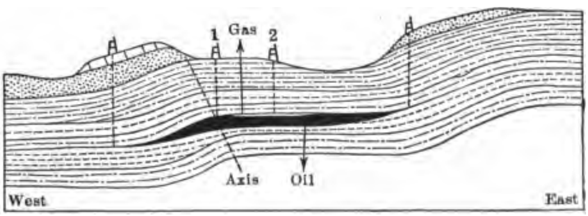


FIG. 20*a*.—Cross-section of a terrace.

and southern Oklahoma the normal dips vary from 40 to 70 ft. per mile. In central Texas 40 to 70 ft. per mile is general; while in Mississippi and Louisiana 20 to 30 ft. per mile are average dips.

To obtain an accumulation of oil on these monoclines it is

essential to find a break or check in this normal dip. Accordingly, if a reversal or flattening of dip is found, an accumulation of oil may take place if reservoir conditions are favorable, and material for the formation of oil occurred in the region.

Terrace structure is practically monoclinal as the major dip is in one direction. The famous Glen Pool of Oklahoma is on such a structure. Terrace structure is a combination of an anticline and a syncline for with such structures the fold has not been

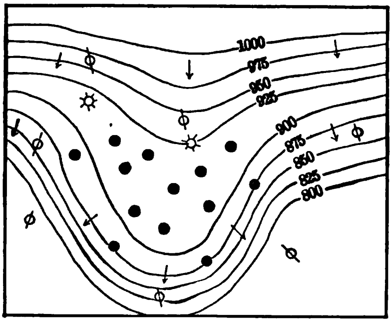


FIG. 20*b*.—Contour map of a terrace.

completed to the point where a well-defined reversal of dip has developed. The flat terrace is shown in Fig. 20*a* by a cross-section, and in Fig. 20*b* by contour lines.

Terraces.—A terrace may be favorable for oil accumulation in shallow regions where water pressures are low, but tests in Oklahoma under favorable conditions show that sands on terraces when found at depths over 2000 ft. have proven small producers. Theoretically there is a good reason for this small production, but in this book the writer does not have time to go into a mathematical discussion. Suffice it to say that if the friction or adhesion of the oil in the sand, and also the cohesion of the particles of oil is sufficient to overcome the difference in specific gravity of water and also the force of moving water, then accumulation may take place.

4. Combinations of Monoclines, Synclines, and Anticlines.—The combination of a monocline, a syncline, and an anticline into one structure is a very common occurrence. Such fields are well illustrated by the Coalinga and the Simi valley oil fields of California, where one finds barren igneous, or metamorphic measures on one side, and a series of folds in the sedimentaries trending away from the igneous or metamorphic rocks. Fig. 21 illustrates a monocline immediately on the flank of the igneous or metamorphic rocks, then a syncline and then an anticline, or a series of them.

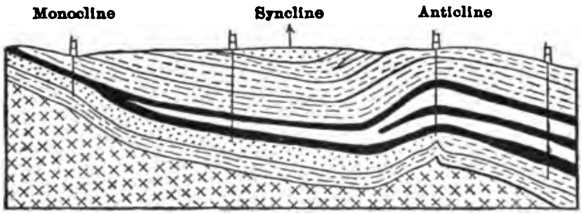


FIG. 21.—Illustrates a monocline, syncline, and anticline combined. Note unconformity, also splitting of sands. (After U. S. G. S.)

5. Domes.—A dome or quaquaversal is a structure in which the strata dip from a central point rather than from an axis or line. Domes are circular or elliptical and are divided into three main classes: (*a*) Anticlinal domes, (*b*) volcanic domes, and (*c*) saline domes.

ANTICLINAL DOMES.—Anticlinal domes are those high points or crests along the top of undulating anticlines. Such forms of domes are very common in California, Oklahoma, Wyoming, Pennsylvania, and throughout the oil fields of India. In many places one main anticlinal fold may continue for 10 to 60 miles and undulate along its course, forming many anticlinal domes or quaquaversals that localize the accumulation of oil. (See Fig. 22*a*). In some cases anticlines intersect as is shown in Fig. 22*b*, and in other cases anticlines merge into one another as in Fig. 22*c*. The resulting structure in each case is generally an anticlinal dome.

Where such a quaquaversal structure stands alone it is simply called a dome. A knowledge of these domes is essential to intelligent prospecting as they make oil territory "spotted."

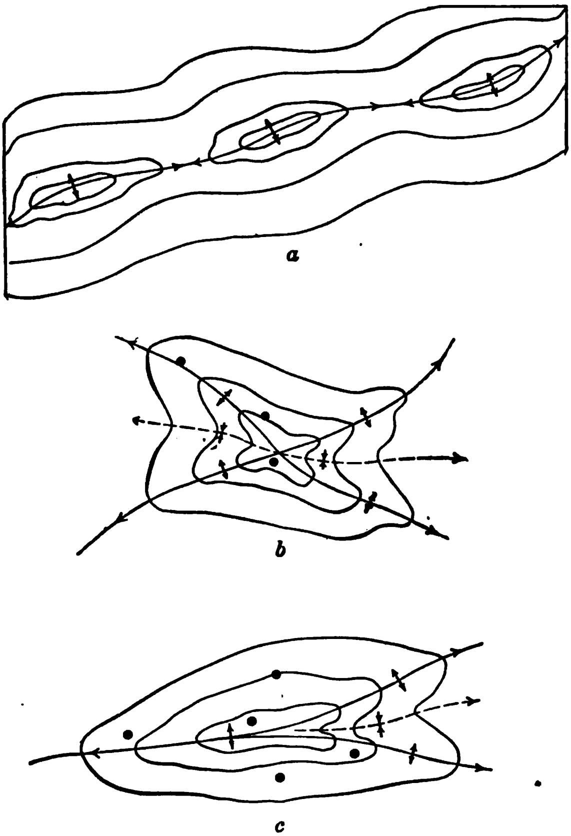


FIG. 22.—Illustrates by contours various forms of doming on anticlines. *a*, domes on major anticline; *b*, dome formed by two cross anticlines; *c*, dome formed by merging anticline.

Realization of this condition will save a great deal of money to oil operators who appreciate the value of structural geology.

As shown in Fig. 44, Chapter V, the dips indicated by the

little darts form an elliptical structure. The plunges of the anticline are shown by the arrows on its axis. The plunges along the axes of the anticline are generally less than the dips away from the axes. Where the plunges are equal to the dips, the domes are circular.

IMPORTANCE IN RELATION TO PETROLEUM.—Dome structure is the most favorable for the accumulation of petroleum, as the oil rises from a large area to the apex of the dome.

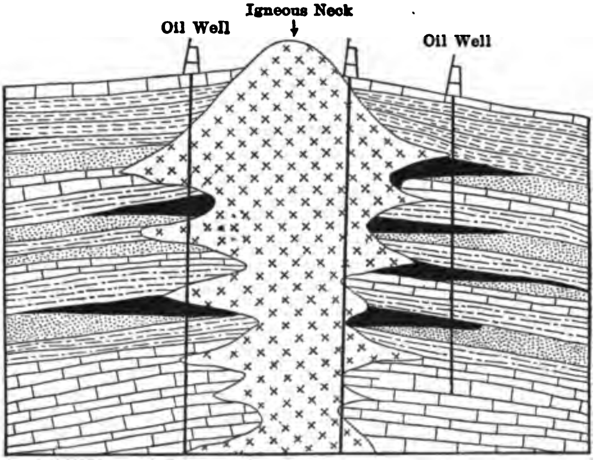


FIG. 23.—Illustrates occurrence of oil around Volcanic neck in Mexico.

The concentration of the oil must necessarily be localized as the tendency of the petroleum, where the oil strata are saturated with water, is to rise to the top of the dome, just as in an anticline the oil rises to an axis. As a result of doming, however, the oil is concentrated into a large reservoir around a central point on the axis instead of being concentrated along the line of the anticlinal axis.

VOLCANIC DOMES.—Volcanic domes are those formed by the intrusion of volcanic matter into and through sedimentaries to form structures like that shown in Fig. 23. The formations

around the cores or necks are bent upward forming domes that act as reservoirs for the accumulation of petroleum. The presence of igneous rocks is by no means to be considered as detrimental to the presence of petroleum where such rocks are intrusives. These volcanic necks are found particularly in the Mexican oil fields.

Saline Domes.—Saline domes have cores of salt at their centers. It is thought by some that underground waters brought great quantities of salt upward through a fault or fissure, and the recrystallization of the salt resulted in so great an expansion that the upward bowing of the formations overlying the salt beds formed domes. (See Fig. 24.) The more plausible theory is that

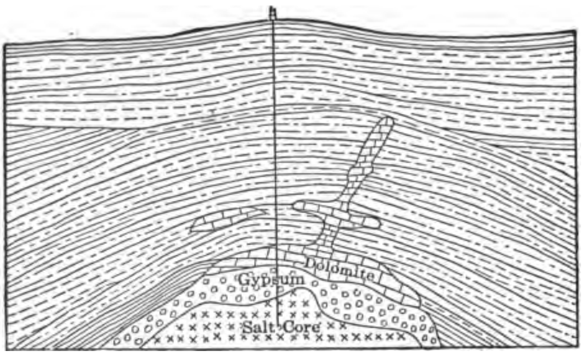


Fig. 24.—Illustrates saline dome. Oil occurs in the dolomite. (After Lee Hager.)

the salt core is but part of a deep lying salt stratum, which has been sharply folded and faulted, and the salt bed encountered in drilling into the heart of the dome is that part of the bed which has been forced up along the fault plane. Such saline domes are common in Texas and Louisiana.

6. Faulted Forms.—Faults are planes of rupture in rocks due to the slipping or sinking of strata upon one another caused by earth movements. Faults are of many kinds, but a few sketches will make plain how they affect oil sands, and why a knowledge

of them is important. Faults are closely related to folds and in most places are indeed but broken folds. Faults at the surface often change to folds underground.

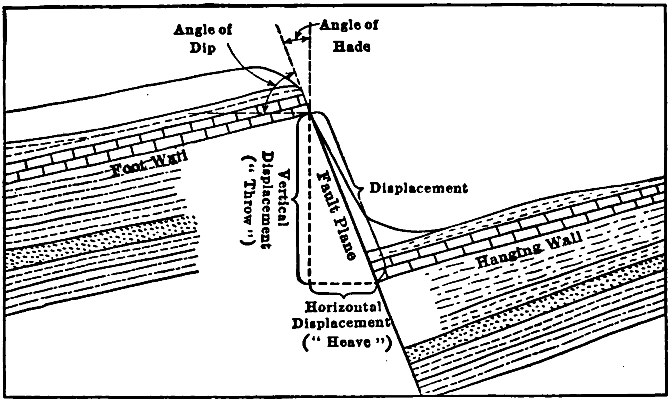


FIG. 25.—A normal fault.

There are two main classes of faults: (1) Normal (see Fig. 25) and (2) Reserved (see Fig. 26). The names of the different parts of faults are given on the figures.

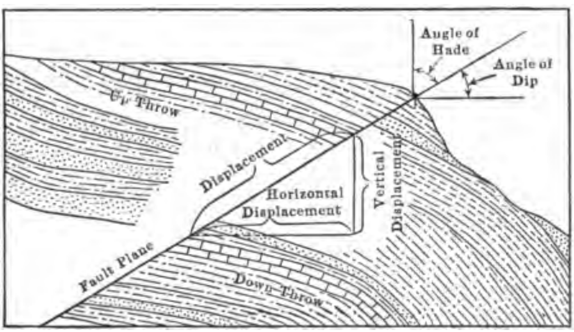


FIG. 26.—A reverse fault.

Where a fault occurs in a field, oil deeply buried may often migrate along the fault plant to beds higher up and thus enable one to procure production at a shallower depth than expected.

Sometimes great masses of brea or asphalt occur along fault lines and extend for a number of miles. In the upper Ojai valley of California, and at Santa Maria, California, such is notably the case

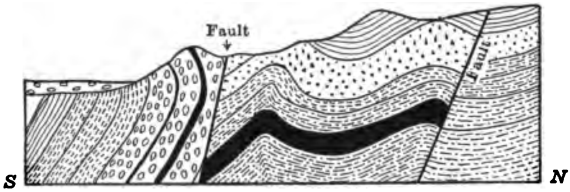


FIG. 27.—Illustrates faulting. Note unbroken anticline.

Effect of Faulting.—The upthrow side of a fault acts like the higher part of an anticline and is, in consequence, the most favorable place on a faulted structure to drill for oil.

In Mexico the largest oil accumulations occur along fault planes. Where a major fault is intersected by a minor fault

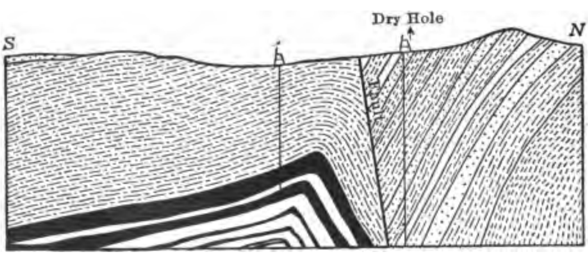


FIG. 28.—Shows effect of faulting. Dry hole to right of fault. (After U. S. G. S.)

the greatest accumulation occurs on the upthrow side of the major and minor faults.

However, where faulting is too severe, it may throw the oil formations very deep on the downthrow side.

In a normal fault, if the vertical displacement or throw is great, the depth to oil may be very materially affected by the

break. Reversed faulting is most frequent in oil-field work, and is due to the pushing of one series of strata over another. Reversed faulting more often occurs on anticlines, normal faults in synclines.

Another classification is *dip fault* and *strike fault.* Dip faults are in the direction of the dip; strike faults are parallel to the strike of the strata. Most productive fields are cut by faults so that they are common features. A few examples of faulted structures are shown in Figs. 27, 28, 29*a* and 29*b*.

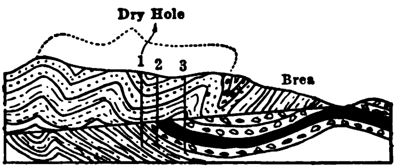


FIG. 29*a*.—Illustrates thrust fault.

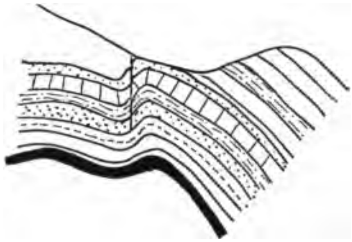


FIG. 29*b*.—Illustrates disappearance of fault with depth.

It must be clearly borne in mind that there are a large number of different forms of structures. Those presented above form only the chief folds that are important for oil men to consider.

Not all Folds are Productive in Oil Regions.—Most oil fields occur on folds, but there are cases where the folds themselves may be well pronounced and in oil bearing regions, but conditions are not favorable for accumulation of oil.

Unfavorable conditions may be briefly classified as follows:

1. Lack of sands, sandstones or limestones favorable as reservoirs. Occur in nearly all oil regions.

2. Sand or sandstones or limestones present but too closely cemented or "tight" to hold oil. Occur in Mid-Continent and Eastern fields.

3. Porous formations with insufficient water in the sands to force the oil in the formations to the top of the folds. Oil in such cases will lie on the sides of the folds close to the syncline.

Such is notably the case in some Kentucky and Pennsylvanian fields.

4. Presence of intrusives or old land masses at the center of the fold. An intrusive in Mexico is illustrated by Fig. 30. Wells Nos. 1 and 3 strike oil; well No. 2 was drilled into granitics. At Zeandale and at Elmdale, Kansas, the expected oil horizons were not found, but horizons thought to be considerably older are far nearer the surface than they should normally occur indicating an old land mass.[1]

5. Erosional or angular unconformities may affect the accumulation of oil as shown in Figs. 31 and 32.

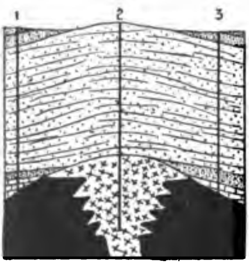


FIG. 30.

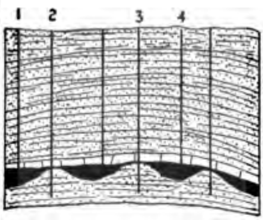


FIG. 31.

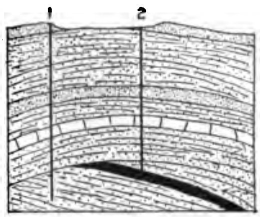


FIG. 32.

In the erosional unconformity (Fig. 31) wells Nos. 1 and 4 are productive; Nos. 2 and 3 are barren. Such a condition is due to the erosion or washing of the earlier beds before the later beds were deposited upon them, leaving an island-like condition.

Angular unconformities (see Fig. 32) may result in a lack of production in a fold. Well No. 1 is barren; No. 2 is productive. Were No. 1 drilled first, the field would perhaps be abandoned. Were No. 2 drilled first, later developments at No. 1 would prove disastrous. Such a condition is the result of folding or tilting of the beds prior to the later deposition and folding.

6. Faulting may affect accumulations, but that has been discussed earlier on pages 61 and 62.

Folds Productive in Spots.—Folds not productive at one place often show good wells at others. This is due to sand conditions.

[1] Granite has been definitely proven in the Onaga, Kansas area bearing out the results at Zeandale.

Porous sands may not lie as blankets over a fold, but occur in spots on the structure. Fig. 33 clearly illustrates this condition. A well-defined structure is shown but it is productive in spots. Gas occurs at the top of the spots, the oil occurs lower, and water below the oil.

One dry hole on such a structure would by no means condemn it.

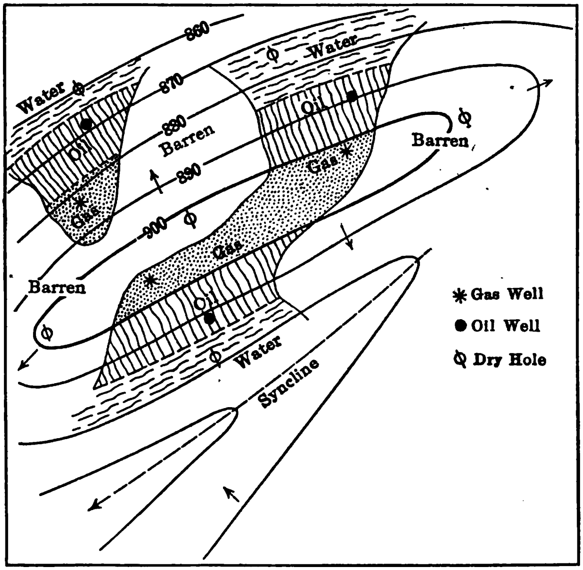


FIG. 33.

STRATIGRAPHIC FORMS—CONDITIONS WHERE STRUCTURE DOES NOT GOVERN

Favorable Reservoirs of Much Importance.—Structure is undoubtedly extremely important in petroleum accumulations, but emphasis must also be placed on sand conditions. Without favorable sand conditions and sufficient material for the formation of oil, structure is worthless. Again, in special cases oil may accumulate where definite geologic structure is not known, but favorable reservoirs have been formed in the sands, as explained below.

Lenses.—Spots.—Accumulations where structures are not apparent occur in numerous places. The peculiar relation is well illustrated in Fig. 34. Where the normal dip of the region is in one direction and a body of sand gradually pinches out or lenses up the dip as in Fig. 35 there is an ideal condition for accu-

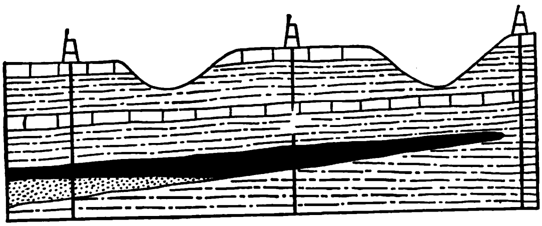


FIG. 34.

mulation of oil or gas. Surface indications show no presence of structure, but an actual test may show oil. A number of the Oklahoma "pools" occur from such causes, notably pools in the Broken Arrow, Morris, and Okmulgee districts, where sand changes are very rapid.

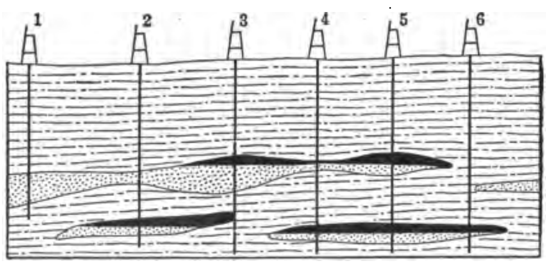


FIG. 35.

Again, lensing of the sand may be due to the playing out of the sand in two directions, as in Fig. 35. In either case conditions favorable for accumulation occur. These sand changes occurred when the sand was first deposited. Similar conditions may be noted along any lake front or sea coast.

Productive spots due not to the thickening of the sand, but resulting from porous spots in tight or closely cemented sands are of common occurrence. The cementation or filling of the pore space between the sands with siliceous or lime salts cause conditions of accumulation similar to those caused by lensing.

Changes in Character of Sands.—Oil sands in themselves vary in thickness even in the same field. A rough sketch illustrates how a sand may change. (See Fig. 35.) At No. 1 there are 50 ft. of sand; at No. 2, there are 20 ft. of sand; at No. 3 the sand has divided or has been split by shale; at No. 6 the upper sand has changed entirely to shale.

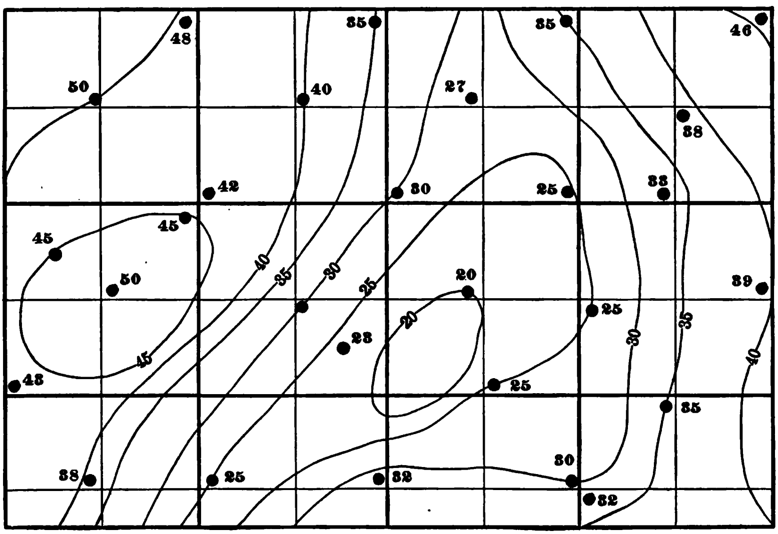


Fig. 36.—Sand map.

Sand Maps.—Wherever possible, sand maps should be constructed. Such maps are explained by contours, but the contour lines here stand for equal thickness of sand and not structure contours. (See Fig. 36.)

Developing Lenses.—The geologist can be of material assistance in aiding the operator in developing lenses.

Suppose a well is "brought in" and upon examination a normal dip condition is found, no structure in other words, then the geologist has the following basis to go on;

Where surface beds show lack of folding, then lensing and spots are the most probable explanations, though unconformities or hidden faults may complicate matters. The history of the oil-fields, if in an old producing area, will serve to guide the engineer as to whether or not lensing is probable.

The history of some pools show the average direction of the productive trend of lenses and spots to be parallel to the old shore lines; in Oklahoma and Kansas this is in a northeasterly direction.

Lenses and "spots" may change very rapidly so it is advisable to keep the wells close together, and develop the "pool" by starting the new tests in close proximity to the producing wells, thus avoiding superfluous "dry" holes.

The presence of water below the oil, or gas above it, in the same sand, the dip of the surface rocks, and the thicknesses of the gas, oil and water impregnated portions of the sand, aid in approximating the "up-dip" or "down-dip" limits of the pool.

The gravity of the oil, if higher than in nearby pools, would suggest a relatively small pool of migratory oil.

CHAPTER V

PROSPECTING AND MAPPING

In searching for petroleum fields, bear in mind the following points:

1. Oil occurs in sedimentary rocks of marine, estuarine and deltaic origin, *i.e.*, beds formed along sea shores, in inland bays, at river mouths, etc.

2. Igneous rocks do not contain oil. Several exceptions to this rule may be cited, but, wherever investigated, the oil was found in conjunction with sedimentaries.

3. Oil is almost always associated with some form of a folded or arched structure. (Anticlines, monoclines, terraces, and domes are favorable structures for the accumulation of oil. Synclines in some cases contain oil.)

4. Petroleum seepages, burned-out shales, oil-stained sands and shales, "gas burns," gas bubbles on water, and asphalt or brea beds are all indicators of petroleum.

By bearing the above points in mind, one can enter a new field and quickly determine whether or not it is favorable for oil.

One first concentrates attention on the sedimentary strata. If igneous formations are known, eliminate such regions from consideration except where volcanic necks or plugs lift the formations to form favorable structures for the accumulation of oil, as occur in Mexico and probably Texas.

If possible, determine whether or not the oil formations are of marine, estuarine, or deltaic origin. Recent lake beds and marshes do not carry oil enough to form commercial deposits. Sandstones, sands, shales, and coarse dolomitic limestones should be sought as favorable reservoirs for oil.

Next look for structural conditions favorable to the accumulation of oil. Such structures are generally folded or faulted with sufficient inclination to the strata to allow oil to rise above

the water and accumulate at the top of the structures. Any of the favorable types of structure shown in Chapter IV afford places for the accumulation of petroleum.

In some regions, notably east Texas and western Louisiana, structural conditions are difficult to determine, due to the flatness of the beds and the effect of erosion, which has made the topography nearly flat.

Oil signs such as seepages, brea beds, and "gas shows" may or may not occur in a region that contains oil in commercial quantities. If the oil-bearing formations are thickly covered with alluvium or other non-productive beds, oil may not appear at the surface though the structure may be favorable to the accumulation of oil. One may, however, find oil in springs, or staining the small streams that cut through oil sands. Oil-stained rock and "gas shows" are favorable signs.

Light gravity oils do not form heavy asphalt beds, as the constituents are readily washed away by water.

The best places to look for evidences of oil are in the beds of gullies and cañons, and on the steep erosion-scarps or cliffs that occur in many regions. Old mines and water wells are all good places to search for oil and gas indications, especially where oil rises on top the water.

Cautions.—Investigators have many times been called to regions where iron and manganese oxides, black alkali, or vegetable stain was thought to be oil. Sometimes gas escaping from springs gives clues to petroleum. Be sure, however, that the gas will burn as many non-hydrocarbon gases, such as sulphur dioxide and carbon dioxide, are non-combustible. Marsh gas from old lake beds has many times been considered a good sign of petroleum and led to oil excitement, but marsh gas occurs in many regions where petroleum does not exist.

Sometimes oil sands are almost white, due to sulphur stains, and one would scarcely suspect them to contain petroleum. Dig into such beds a few inches and chocolate, greenish, brown or black-colored oil sand may appear.

An interesting and valuable test for oil is given below:

TEST FOR OIL IN ROCKS

(After *E. G. Woodruff*)

1. Select a representative specimen of rock to be tested. To secure a representative sample, it is generally advisable to secure several samples as large as one to five pounds.
2. Break them up, thoroughly mix the pieces. If sand, mix the sand.
3. Dry the sample in the sun or over a radiator. Do not dry it over a fire; to do so may drive the oil from the rock or sand.
4. Crush the sample to a powder. Mix the powder. Loose sand does not need to be crushed.
5. Place about a tablespoonful of the sample in a bottle. Pour chloroform or carbon-tetra-chloride over the sample until it is thoroughly saturated and there is about a half tablespoonful of the liquid above the crushed rock or sand. Cork the bottle, but not too tightly. Shake occasionally for fifteen or twenty minutes.
6. Place a white filter paper in a glass funnel with a white enamel dish below the funnel.
7. Pour the contents of the bottle into the funnel. After the liquid has filtered through, place the white dish in a window where the liquid can evaporate.
8. Examine the filter paper. If the rock contains more than a trace, there will be a brown or black ring on the filter paper.
9. After the liquid in the dish has evaporated, examine the remaining substance. It is the petroleum which was in the rock.

   Apparatus needed:

   One dinner plate upon which to dry specimens.

   Some means for crushing rock.

   One or more bottles, 4 or 6 oz. size (with corks) in which to treat the rock.

   Chloroform or carbon-tetra-chloride.

   One glass funnel three or four inches in diameter.

   Two dozen round filter papers, six inches in diameter.

   Two or more white dishes, the small serving dishes, such as are used at hotels, are good; they can be purchased at a ten-cent store.

After the investigator is fully satisfied that a region is worth investigating carefully, the hard work begins. Detailed structure is mapped and a study made as to the various types and forms of structure. A geological map is constructed and detailed cross-sections worked out. In making such a map and cross-sections, one resorts to the methods and symbols shown in this chapter under "Mapping." Such work carefully done enables one to determine the following points:

1. The places worth testing with a drill, *i.e.*, the anticlines, terraces, monoclines, or domes.

2. The presence of faults, synclines, and intrusives that may adversely or favorably affect the accumulation of petroleum. As noted before, faults, synclines and intrusives do not necessarily adversely affect a field, but they sometimes do.

3. The relative ages, thicknesses, and character of the formations of the district. Such information is very valuable when extensions of an oil field are considered. Oil found at certain horizons in one district does not necessarily occur at the same horizon in other districts, although it often does.

4. Length and breadth of the field.

5. The accessibility of the region, road conditions, fuel supply, water, and ease of securing supplies are also factors that must be seriously considered before actual drilling commences. Some districts are geologically favorable for oil, but when haulage of drilling materials costs $20 to $30 per ton it will not pay to prospect with a drill.

Prospecting by means of crooked sticks, magnetic instruments, and electrical contrivances is sometimes employed. Where the examining man is an expert oil man, he may determine favorable oil territory despite his instruments, but generally such men are "fakers," pure and simple.

Before actually starting drilling in a new country, spend some time prospecting. More money can often be saved by a few days spent in faithful prospecting than by spending $50,000 to put down a drill hole.

The appended table taken from Cunningham Craig's "Oil Finding" may be of service.

TABLE IX.—FAVORABLE AND UNFAVORABLE INDICATIONS OF OILS

Favorable			Unfavorable	
Always	Usually	Sometimes	Usually	Always
Shows of oil with strong gas in thin porous beds along impervious strata	Shows of filtered oil with gas.	Shows of oil with very little gas.		Light shows of oil in thick porous beds with water or brine.
	Evidence of estuarine or deltaic conditions.		Evidence of entirely marine conditions.	
		Beds of gypsum or rock salt.		
	Shows of gas below or in a thick argillaceous series.		Brine.	
	Shows of partially inspissated oil near the surface.		Shows of partially inspissated oil deep down.	
				Water-sands below a thick argillaceous series.
		Lignites or coal, fossil resin, sulphur or sulphuretted hydrogen.	Sulphuretted hydrogen accompanied by hot water.	Hot water with neither oil nor gas.
	Gas in slightly porous strata with pressure increasing downward.		Gas shows accompanied by water in porous beds among impervious beds.	
	Ozokerite or manjak veins.			

MAPPING

Before proceeding further with a detailed description of oil-field structure it is well to study the graphic representation of typical structures by means of topographic and of geologic symbols. The United States Geological Survey has made excellent geological maps of most of the American oil-fields, and for that reason the oil men should learn to interpret the maps to best advantage.

Topography.—Topography is the description of the earth's surface and the study of the surface forms, hills, valleys, drainage, etc. Fig. 37 illustrates a method of expressing surface features by a topographic map. The hills are shown by means of contour lines, which are lines connecting points of equal elevations above mean sea level, the lines being drawn at regular vertical intervals. The numbering on the lines indicates the heights above mean sea level.

A skilled reading of topographic sheets often enables one to point out anticlines, synclines, and faults without even knowing the district.

It is more important for the oil-man to study sedimentary topography than to study igneous topography. The following brief summary may be of value:

Granitic and volcanic rocks give a rugged broken surface. Shales and soft sandstone erode to form rounded hills and wide valleys. Hard sandstone, limestone, and conglomerates form steep-faced hills and escarpments when the dips are moderate; when the beds dip steeply, erosion will in time wear down the soft shales and sandstones to a bed of limestone or sandstone that will not readily wear away. In such cases where the beds have been folded the limestone may occur higher in the hills than in the valleys, a case where a "topographic high" is a "structural high."

Hard beds erode slowly and soft ones rapidly, giving a short bench-like form to the hills, where hard beds are present. Terraces of this kind are very common. By watching such terraces

one can trace beds over considerable distances, even though rock exposures are not clearly visible or are covered with vegetation. Hills capped with hard limestone or sandstone beds often reflect the dips very accurately, so that one can see the slope with the eye.

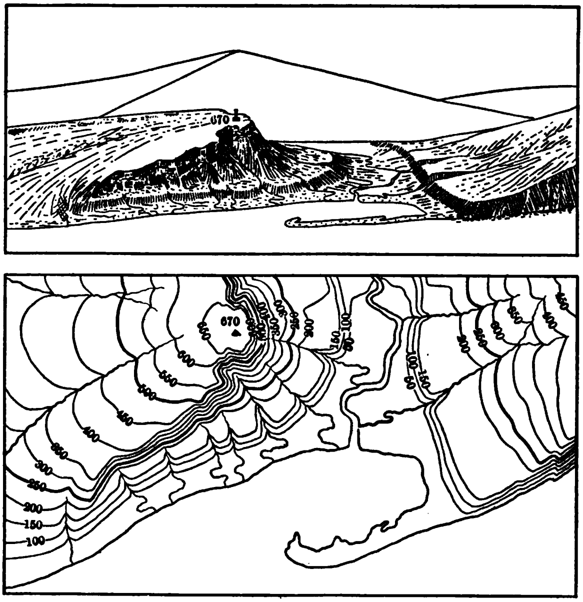


Fig. 37.—Ideal sketch and corresponding contour map. (After U. S. G. S.)

Drainage.—In studying probable prospective territory it is often of service to study the drainage lines. The main streams in many regions cut across the major folds, and the smaller and secondary streams, follow the major structure, such as synclines, anticlines and faults.

In some places the main stream follows the synclines and crosses the main anticlinal folds at the saddles or low places on the anticline. High divides often point to anticlinal conditions. No rule

can be stated, however, to cover all regions, so each region must be considered as a distinct topographic unit.

Underground structure is generally reflected by the surface. This truth must not be forgotten. Hills and mountains often reflect underground conditions so that wherever one sees hills he naturally looks for some sort of structural change, although this is not generally the case.

Valleys are many times synclinal. Also the crests of many anticlines have been eroded or washed out to form valleys, and the apices of domes are eroded in the same way. In such cases, while the flanks of the anticlines may be high, the centers are cut by valleys. Faults may also cause valleys by leaving depressions, or subjecting some parts of the structures to more rapid erosion than other parts.

Dip Slopes.—The dips of the beds in Kansas, Oklahoma, and the Pennsylvania area of Texas are generally reflected in the table-like tops of the hills which are capped with sandstones or limestones, that accurately delineate the dip of the beds. This fact has proven of such great value to the geologist that it has enabled him to work country in several days time, that would otherwise require several weeks.

Erosion Features.—Erosion in synclines may be deeper than in anticlines, thus exposing older beds. This may lead to confu-

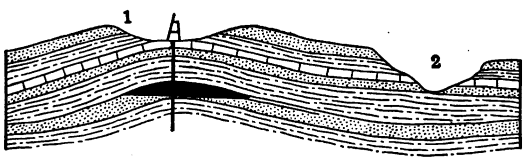


FIG. 38.—Shows older beds exposed in syncline.

sion as one naturally expects to find a domed condition where the oldest beds are exposed; Fig. 38 shows this condition. The beds at 2 are older than at 1. This is often the case in limestone districts, as there is greater solution action on the limestone, due to the more plentiful supply of water in the synclines. In Cali-

fornia, Wyoming and southeastern Oklahoma, in fact, wherever the folding is intense, the occurrence of the older beds generally spells a domed condition, but such is not true by any means in Kansas and Northern Oklahoma where the dips are very gentle.

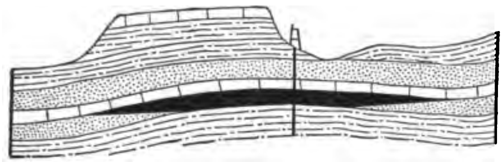


FIG. 39.

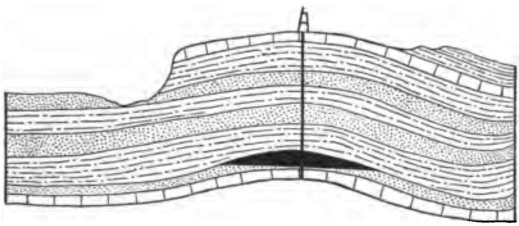


FIG. 40.

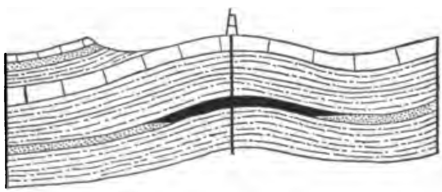


FIG. 41.

Fig. 39 illustrates a topographic condition that is found in Oklahoma at Glenn Pool, the New York Pool, and several other places. The dip to the East may be called practically flat. In such cases one often finds a high escarpment to the west of the field with low hills or a flat bottom to the east.

Another freak of erosion is to find a "structural high" eroded on one side as shown in Fig. 40. Such occurrences are not

rare by any means. A good example is the big dome in the north end of the Cushing oil-field of Oklahoma.

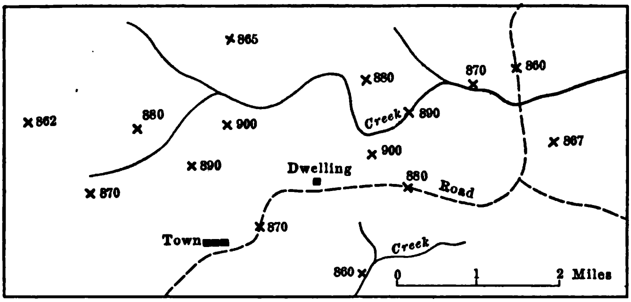


FIG. 42*a*.—Sketch map showing numbered elevations on the same outcropping stratum at different points.

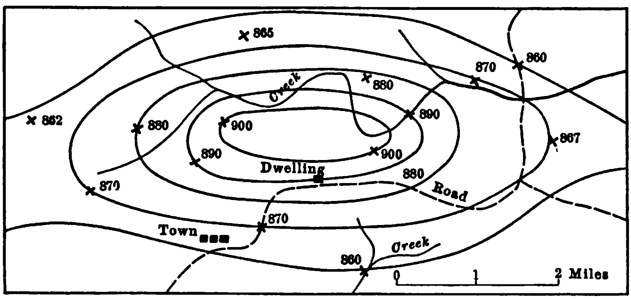


FIG. 42*b*.—Same map as Fig. 42*a* with structure contour lines connecting points of equal elevation thus outlining an elongated dome.

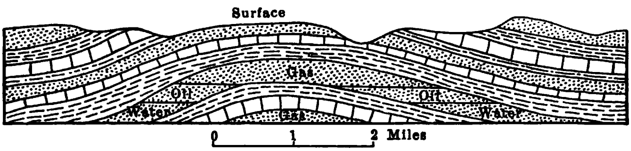


FIG. 42*c*.—Lengthwise section of structure shown in Fig. 42*b*. (After J. H. Gardner).

In Fig. 41, the bed exposed at the top of the structure is a limestone. In this case the upper beds that once covered the fold have been worn away to the heavy limestone which was in time

eroded, leaving a high surface elevation which is also a structural "high," *i.e.*, a dome or anticline. Such conditions are common in Kansas and Oklahoma, where limestones or close-grained sandstones are often found capping the structures.

Vegetation.—It is interesting to note that in some localities the wild vegetation varies with the rock below the soil. Thus limestones give grassy slopes on top the beds, and steep barren faces; sandstones grow scrub oaks. Again shales give slopes which often carry little or no vegetation upon them. Pure shale is too compact for rank vegetation.

Structure Contours.—Contour lines as used in expressing topography are also employed in expressing the geologic structure of a region or in mapping a fold. The contour lines in such cases do not, however, show the true topography of the surface, but the elevations of some key bed of rock before erosion took place.

Structure contours are of three kinds:

1. Those made from surface exposures only, and especially valuable in "wildcat" territory.
2. Those made from well records.
3. Those made by combining surface exposures and well records.

In all cases the method of mapping is very similar. A key bed, characteristic at the surface or underground, is chosen as a starting point. The beds above or below this key bed are accurately measured and the intervals between the beds noted. The elevations of the beds above sea level are obtained by measurements with the aneroid barometer, spirit level, or alidade.

The key bed at the surface is followed along the outcrop, and elevations obtained upon it. When the key bed is buried, hidden or eroded away some other bed above or below the key bed is followed. In the final checking and map making, the beds are all referred back to the key bed by adding or subtracting the intervals between them. Intervals below the key bed must be added and intervals above the key bed must be subtracted.

Figs. 42*a*, *b*, and *c* show the development of a contour map.

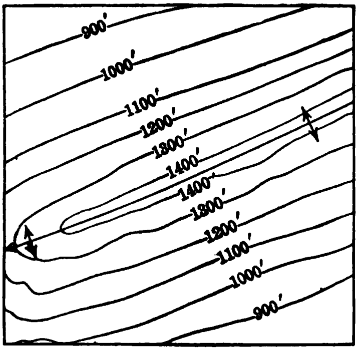


FIG. 43a.—Shows method of expressing an anticline by contours.

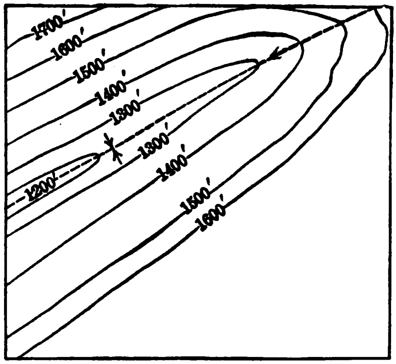


FIG. 43b.—Shows method of expressing syncline by contours.

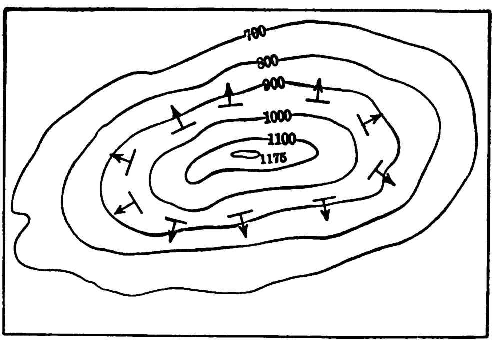


FIG. 44.—Dome shown by contour lines.

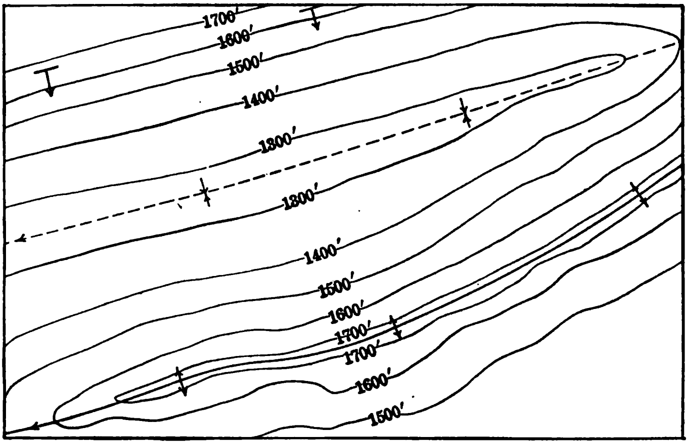


FIG. 45.—Anticline, syncline, and monocline.

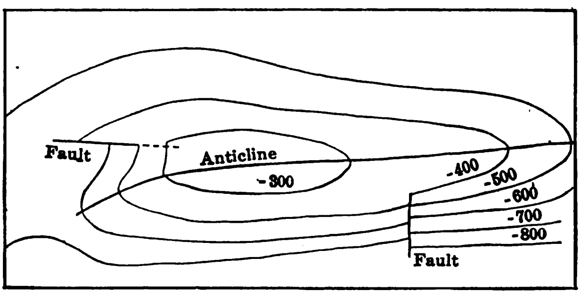


FIG. 46.—Contour map of faulted anticline. (After U. S. G. S.)

The elevations are marked on Fig. 42*a*, the contours are drawn on Fig. 42*b* and a cross-section, much exaggerated in vertical scale, is shown in Fig. 42*c*.

Figs. 43*a*, 43*b*, 44, and 45 also show representation of an anticline syncline, monocline, combination of the above three, and a dome all by contour lines.

Such contour mapping is an ideal system for accurately mapping regions of low dips as in Pennsylvania and Oklahoma. There are places, however, where the underground structure differs materially from surface structure. Where hidden nonconformities or faults complicate underground structure, they often show on the contours. (See Fig. 46.)

Convergence.—If as in Fig. 47 the interval or distance between two beds *a* and *b* gradually diminishes the beds are said to converge. This is due to unconformity, to overlap, or to thickening or thinning of the beds below the key bed.

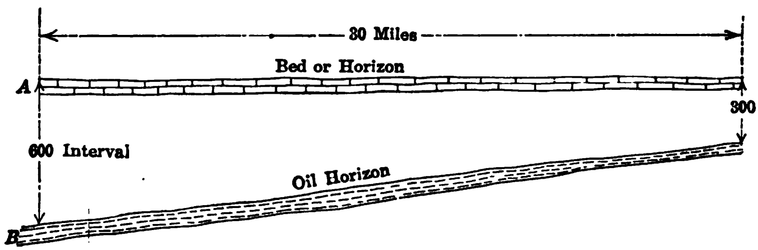


FIG. 47.—Convergence 10 feet per mile in 30 miles.

The best example in the Mid-Continent field is the difference in interval between the Oswego limestone and the Bartlesville sand. In the Nowata field the interval is 400 ft. At Glenn Pool 50 miles South the interval is 600 ft.; a difference of 200 feet. The average rate of thinning to the north is 4 feet per mile.

Convergence may cause surface folding to be different from underground folding, though where the surface dips on local folds are 80 to 100 ft. per mile, and the convergence but 5 to

10 ft. per mile, the underground structure will be only slightly influenced by convergence; and for all practical purposes convergence can be neglected.

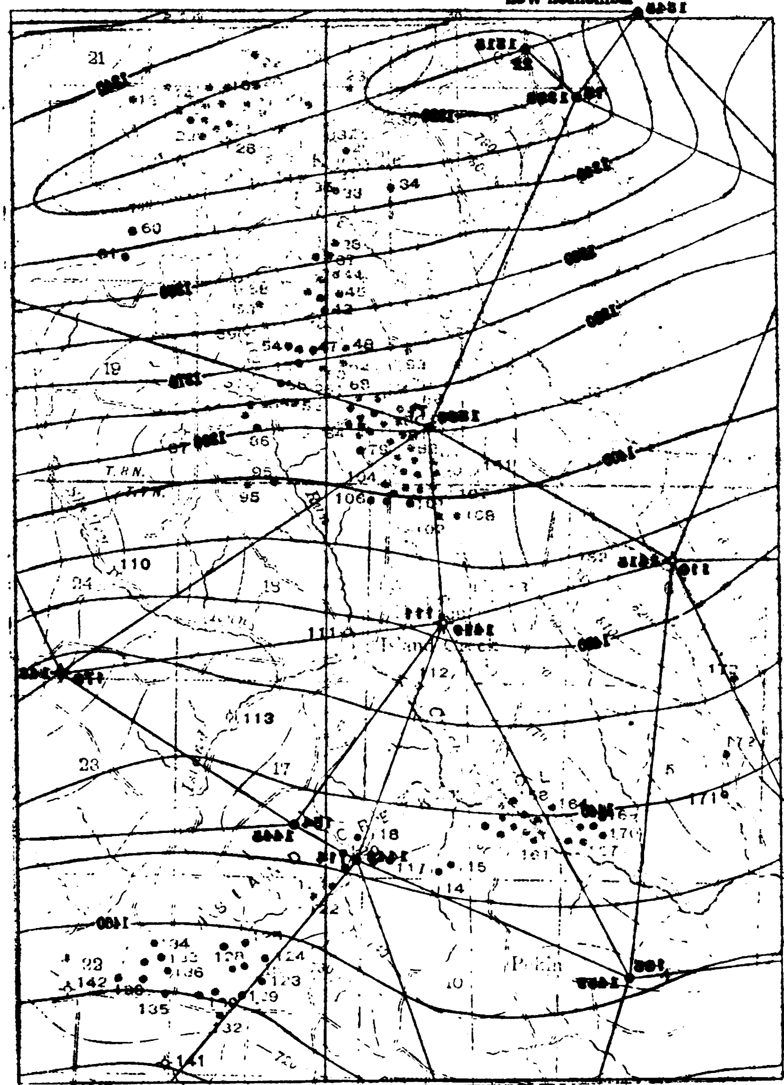
The construction of a convergence sheet and its application is explained below. The text is taken from Bulletin 318, United States Geological Survey, by W. T. Griswold and M. J. Munn.

Construction of Maps.—The work of making a map of a particular stratum lying at a considerable depth below the surface consists of three distinct steps—first, careful contour mapping of some prominent surface beds, called the "key horizon;" second, the more difficult task of ascertaining the distance between this key horizon and the producing oil sand below and the amount and direction of the variation in this distance; third, the application of a correction to the surface mapping equal to this convergence, so that lines drawn on this map connecting points of equal elevation above the sea (contour lines) will show the true shape of the surface of the oil sand.

Structural Map of the Key Horizon.—On the completion of the field work, as previously described, the geologist had a topographic map of the area on which the horizontal location and the elevation of the outcrops of different marking strata are shown at hundreds of points. (See Fig. 48.) By a comparison of these outcrops, the intervals between different marking beds were obtained. One bed was selected as the key horizon, usually that outcropping over the greatest area. By adding to or subtracting from the elevation of outcrops of other known beds the distance they have been found to be below or above the key horizon, the elevation of that stratum was obtained at a great many points. By drawing lines connecting the points of equal elevation, a contour map of the key horizon was produced.

Convergence Map.—A knowledge of the variation in distance between the key horizon and the oil sand was gained from the records of wells in different parts of the area, and without these records it would be impossible to make any illustration that would show the form and position of the sand, unless it were exactly parallel with the key horizon.

FIG. 48.—Contour Map of Key Horizon, which in this case is the Pittsburgh Coal.


T. 8 N.
T. 7 N.

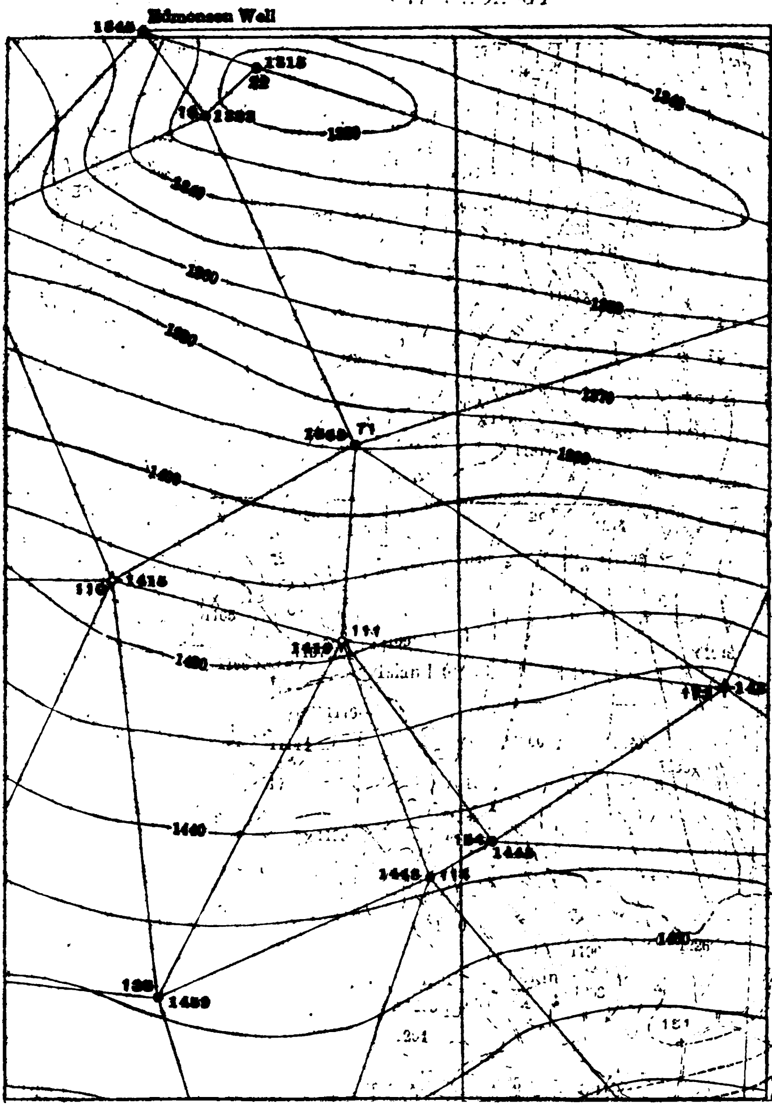


Fig. 49.—Convergence sheet of Fig. 48 shows distance from Pittsburgh Coal to top of Berea Oil Sand.

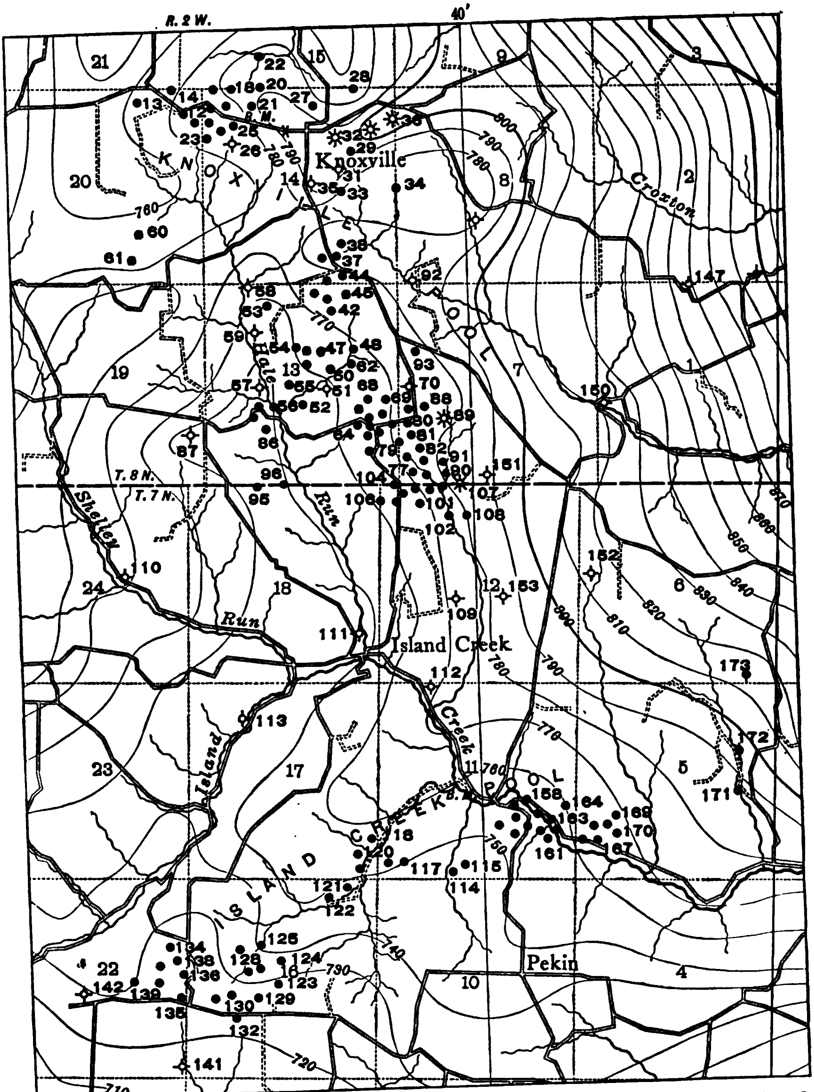


FIG. 50.—Contour lines drawn on Oil Horizon, which in this case is the Berea Oil Sand.

To make use of the well records and construct an actual map of the oil-bearing sand, the following method was employed: On the map of the structure of the key horizon were plotted all the wells drilled within the area. As the elevation of the mouth of each of these wells had been determined, the position of the key stratum with reference to the mouth of the well was obtained directly from the map, and with this information the distance from the key stratum to the oil-bearing sand at this point was obtained from the record of the well.

By making this computation for each well of which a reliable record could be obtained, the distance from the key horizon to the oil-bearing stratum was obtained in different parts of the area. Generally this distance is not the same at different wells, but decreases in one direction or the other.

The correction for the convergence between the key horizon and the oil sand is applied by means of a mechanical drawing called a "convergence sheet." (See Fig. 49.) This drawing was made on tracing cloth by connecting the location of the oil wells from which reliable records had been obtained by straight lines. The lines were then divided proportionately to the amount of convergence found between the two wells, so that each division on the lines would represent the increased distance of 10 ft. between the key stratum and the oil-bearing sand.

After all the lines connecting the different wells had been thus divided, the points that show an equal distance from the key stratum to the oil sand were connected, and a drawing was built up that, when placed over the map on which the elevation of the key stratum was noted at many different places, showed directly what distance should be subtracted from each elevation of the key stratum to make it equivalent to the elevation of the oil sand at that point.

The regularity and uniformity of this mechanical drawing shows whether it is possible, or not, to make a map of the oil sand that will be of any practical value. If the distance between the 10-ft. lines, which are called isochor (equal space) lines, is regular and the decrease is uniformly in one direction, a map of the

lower sands can be made practically correct. If, however, the distance from the key horizon to the sand decreases first in one direction and then in another, the lines on the convergence sheet will run in circles and show that there is little use in trying to interpret the structure of the sand from a map of the surface structure. It can hardly be hoped that the wells used have been located at the exact point of the greatest distance between the two strata. In all probability the resulting convergence is incorrect over limited areas.

The amount of convergence per mile is another condition to be considered. If it amounts to 50 or 60 ft. to the mile, there is little probability that the resulting map of the sand will be correct within a limit of 20 to 30 ft. If, however, the convergence is only 10 or 20 ft. to the mile, the resulting map should be of the same degree of accuracy as the map of the surface structure.

In making maps of subsurface strata in areas that have not been productive, most of the records used for making a convergence sheet must be taken from "wild-cat" wells. In certain cases it is difficult to procure the records of such wells, and often the best that can be obtained is the depth, from memory, at which the sand was found. Here is a source of serious error, for a mistake in this distance may make the resulting map incorrect for a considerable distance about the well.

In making a subsurface map, full knowledge should be had of the well records used for constructing the convergence sheet, and if any reliable records have been thrown out whose distances would change the convergence sheet, the reason for discarding them should be given. In selecting the records for the construction of a convergence sheet it is desirable to consider wells from which a good record is obtainable, and those that are located near the outcrop of an easily recognized surface stratum.

Map of Oil Sand.—With the convergence sheet completed, the operation of making a contour map of the oil sand is very simple. The tracing is placed over the map on which are noted the elevations of the key horizon. From each of these elevations

the amount shown by the convergence sheet was subtracted. This gave the elevation of a point on the oil sand. By connecting the points of equal elevation by lines, a contour map of the oil-bearing sand was made. (See Fig. 50.)

Geological Map.—The accompanying geological map and cross-sections (see Figs. 51 and 52) illustrate the structure of a typical region. Symbols, a fault, and several formations are shown. A thorough study of this map and the cross-sections will enable one to comprehend the U. S. Geological Survey's geological maps.

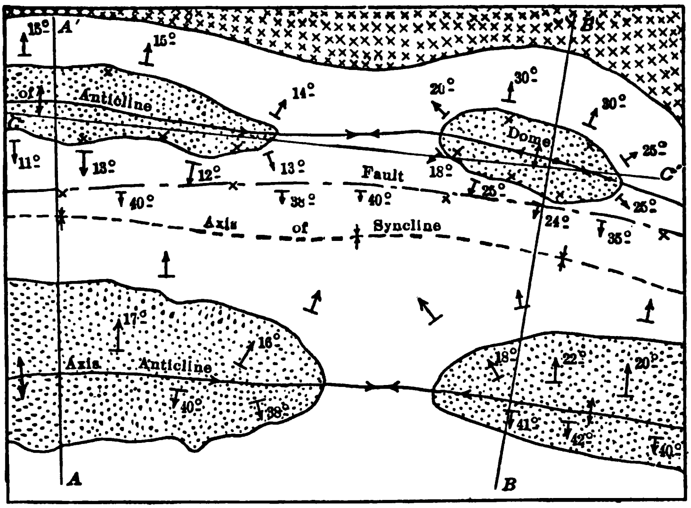


FIG. 51.—Geologic map.

Contact lines are lines marking the boundary of geological formations of varying ages, and on maps are represented as in Fig. 51. Other symbols are used to suit varying conditions.

Colored maps and cross-hatching are generally used to make mapping clear. The table (see Fig. 53) explains the symbols used and followed in this book.

Photography.—The use of photographs to illustrate structures is very useful where the folds are small enough to be readily

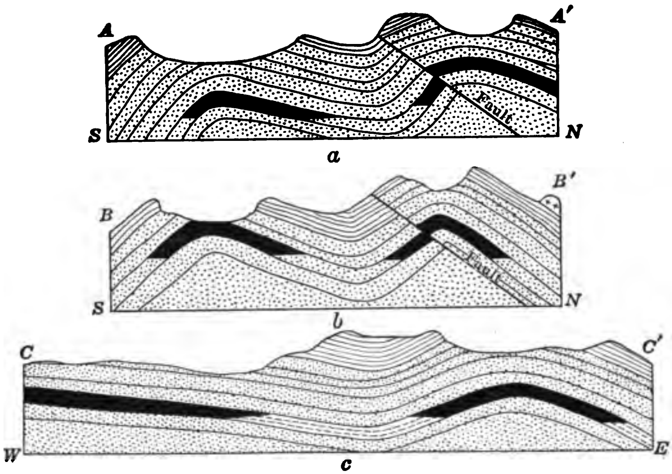


FIG. 52.—Cross-sections along lines *A-A'*, *B-B'*, *C-C'* in Fig. 51.

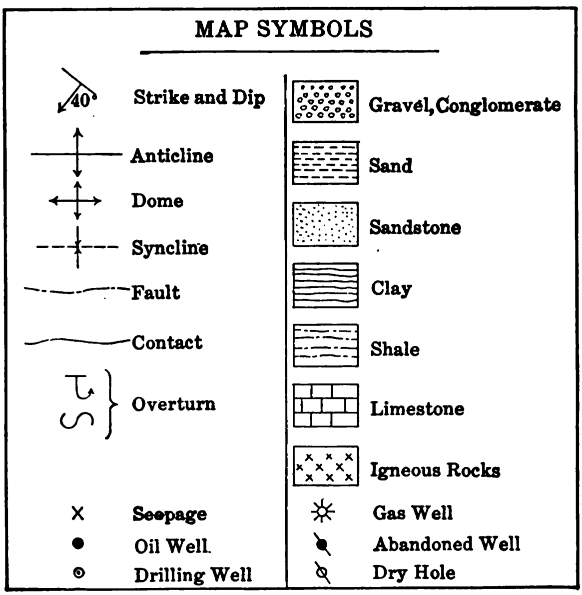


FIG. 53.—Symbols used in mapping.

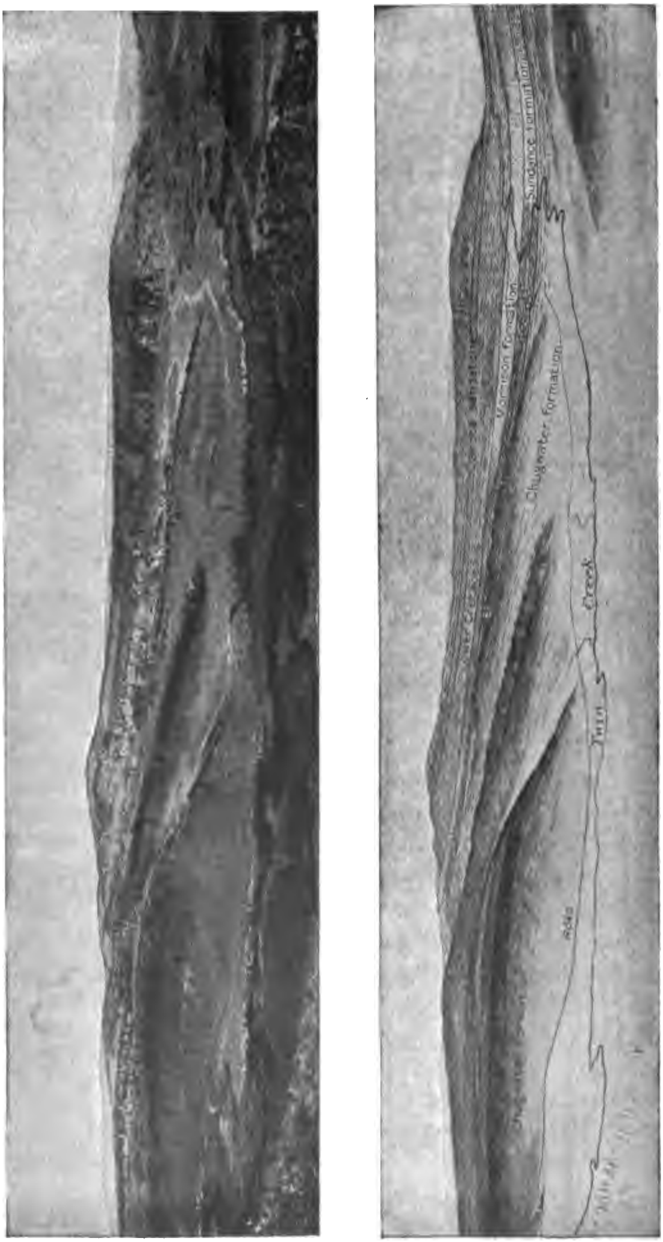


FIG. 54.—Illustrates use of photography in outlining formations. (After U. S. G. S.)

photographed. An illustration of such usefulness is given in Fig. 54 in which a photograph and a sketch from the photograph both depict structural conditions.

Stereograms and Cross-sections.—Stereograms are graphic models of structure and are sometimes used to explain underground conditions. (See Fig. 55.) The figures in Chapter IV show a means of explaining underground structure by using cross-sections.

Models.—Miniature models like those used by architects in depicting large buildings are coming into use to illustrate underground conditions. Models have also been employed in mining work for some years but their use in oil fields has not become general.

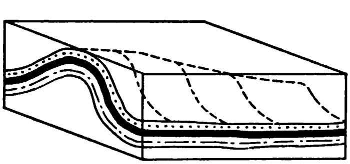


Fig. 55.—Stereogram of plunging anticline.

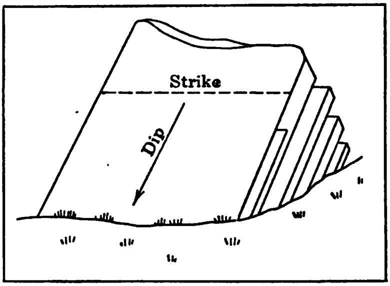


Fig. 56.—Strike and dip. (After Geikie.)

The employment of models is simply a graphic method which simplifies explanations to the layman, and enables the practical operator to see conditions at a glance. In using this method, miniature representations of the surface and of the oil and of the water sands are constructed of paper, of wood, or of wire and sometimes enclosed in glass cases. Such models take considerable time to make, and require considerable cost but are excellent for class-room studies, for illustrating legal phases of oil-field practice, and for use in explaining properties to stockholders, directors, prospective investors, etc.

Dip (See Fig. 56).—The inclinations given to the beds forming the earth's surface are called dips and are measured

by a clinometer. Dips are expressed in degrees measured from the plane of the horizon, such as 20°, 45°, 90°. Sometimes they are expressed as slopes of 17 per cent., 25 per cent., etc., which is the same system as used in road and street construction (see Table XI) and is very convenient in structural contouring.

In Pennsylvania, Ohio, and Oklahoma, dips not exceeding 30 ft. per mile are common. A slope of 40 ft. per mile is sufficient to localize the petroleum in some fields. In the Pennsylvania fields 250 ft. per mile is considered a steep dip or slope. The gentler dips of the Eastern and Mid-continent fields are in direct contrast to the steep dips of California. Dips of 45° to 90° are not at all uncommon in many California fields. Dip per 100 ft. is often used instead of dip per mile, as the changes in slope are generally very rapid and will not generally continue uniform for distances over ½ mile, and in many cases not so far.

In reading dips the tendency is to overestimate, rather than to underestimate the amount of dip. This is true because the surface beds often weather and slide, showing exposures with greater dips than the true dips. The most accurate dips are those obtained by sighting over considerable distance, say one-fourth to several miles. The dips of minor folds are sometimes observed and mistaken for the dip of major structures. One must especially guard against confusing such dips.

Strike (See Fig. 56).—"A horizontal line drawn at right angles to the dip is called the strike of the rocks. Strike may be conceived as always a level line on the plane of the horizon, so that no matter how much the group may undulate, or the outcrop may vary or the dip may change, the strike will remain level or horizontal." The direction of strike is expressed in directions of the compass as N. 25 E. or S. 85 W.

Earth Curves.—Remember that all folds are parts of earth curves. For this reason a dip at one point on the curve increases or decreases at other points. As the locus or central point of this curve is somewhere in the center of the fold, the dips along a horizontal line will show different values for each

stratum. A knowledge of this fact shows that dips must be used very carefully to obtain accurate results.

Plunge.—Plunge is the pitch of the whole formation along the strike. Thus in anticlinal domes there is a pitch along the strike of the anticline. This pitch is called the plunge to distinguish it from the dip, at right angles to the strike. Both dip and plunge are measured in a similar manner. (Fig. 55 illustrates a plunging anticline.)

TABLE X.—CONVERSION OF PER CENT. GRADE TO ANGULAR INCLINATION

(After Hayes)

Per cent. grade	Angular inclination	Per cent. grade	Angular inclination	Per cent. grade	Angular inclination
1.0	35′	7.00	4°	13.00	7° 25′
1.50	52′	7.50	4° 15′	14.00	8°
1.75	1°	8.00	4° 35′	15.00	8° 30′
2.00	1° 10′	8.50	4° 50′	15.85	9°
2.50	1° 25′	8.75	5°	16.00	9° 5′
3.00	1° 45′	9.00	5° 10′	17.00	9° 40′
3.50	2°	9.50	5° 25′	17.65	10°
4.00	2° 15′	10.00	5° 50′	18.00	10° 15′
4.50	2° 35′	10.50	6°	19.00	10° 45′
5.00	2° 50′	11.00	6° 15′	19.45	11°
5.25	3°	11.50	6° 35′	20.00	11° 20′
5.50	3° 10′	12.00	6° 50′	21.00	11° 50′
6.00	3° 25′	12.25	7°	21.25	12°
6.50	3° 45′	12.50	7° 10′	....	....

CHAPTER VI

LOCATING DRILL-HOLE SITES

LOCATING SITES FOR TEST HOLES

The location of drill-hole sites depends upon many factors which for convenience may be divided into two classes:

(1) Those where structural features are evident; as where outcroppings are in evidence, and where one finds oil seepages, asphaltum residues, etc.

(2) Those where structural features are unknown; as where structural features are covered up, though gaseous emanations, oil on spring or lake waters, and other oil signs may be known.

Where structural features are favorable for oil, one generally finds some oil signs. Where dips are known and structural features are outlined, locating becomes merely a question of judgment, governed by the following mechanical and geological factors:

(1) Degree of dip of strata. (2) Thickness of overlying cover. (3) Deformation of strata, *i.e.*, sudden change in dips due to: (*a*) faulting, and (*b*) minor folds.

Locations Where Outcroppings are Evident.—*Rule.*—Locate a test well down the dip (see Fig. 57) from an oil seepage, or other oil sign at the outcropping of oil sand. This simple rule has often been disobeyed with a consequent loss of thousands of dollars.

In many cases, drill holes are started above the outcrop of the oil sand. Negative results were thus assured from the beginning in the top sand, though production was sometimes obtained in the sand below.

Where outcrops are not in evidence, or the desire is to drill for oil measures other than those outcropping, the rule given above

cannot be applied. In such cases, the structural features (anticlines, or some modifications of anticlines) are carefully determined by surveys.

When the surface axis of the anticline has been determined,

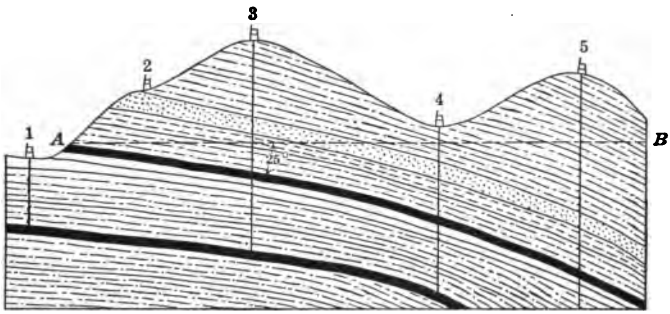


FIG. 57.—Shows effect of topography in choosing well sites.

the dips of the sides or flanks must be known to determine the shape of the anticline and the inclination or dip of the beds away from the axis.

If the anticline is symmetrical, place the test hole on the axis.

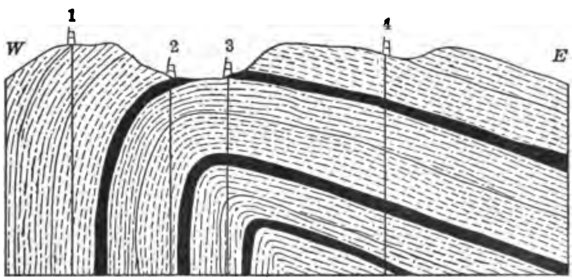


FIG. 58.—Illustrates locating wells on an asymmetrical anticline.

If one flank of the anticline is much steeper than the other, place the wells on the flank of less inclination. (See Fig. 58.) It is readily seen in this case that the east slope gives a wide expanse of comparatively shallow territory, and that the west slope

gives a narrow belt that rapidly becomes very deep. The underground axis of each oil sand lies further east than the axis of the sand above. By drilling on the gentler slope there is less liability of missing any oil sands than by drilling on the west slope. Bear in mind in all the above cases that the apex or high point of the simple anticline, or the apices of domes, are to be chosen in preference to the low places on the axis of the fold. In other words the top of the fold across the line of strike is not alone a sufficiently good place on which to locate a well but the position along the strike must also be taken into consideration.

It is not always best to locate the first well directly on the apex of the structure for in some cases such domes are unsaturated with oil at the apices though gas occurs there. To obtain oil locate further down the dip or the plunge of the structure.

Depths of Prospect Holes.—The distance of a drill hole from the outcrop should be such that oil may be reached at a minimum depth and at least cost.

One should not expect sensational results from a prospect hole. Ten to twenty barrels of light gravity oil (25° and over) in shallow territory, 500 to 1500 ft. in depth, proves that the field has commercial value, if one can gain this depth at a moderate cost. The depth of the hole varies with the dip and the distance from the outcrop.

Where there is an added overburden of a thousand feet or more, as is the case in some fields, depths become much greater and drilling more expensive. This question, however, will be more fully discussed below.

Effect of Topography on Depth to Oil.—The differences in thickness of beds overlying the oil formation has a distinct effect on depths to the oil sand, as shown in Fig. 57. *A* indicates the outcropping of the sand, the angle 25° shows the dip of the strata, and the line *A*-*B* corresponds to the horizon. Without the additional overburden above the line *A*-*B* the depths would be influenced solely by the dip, and the distances from the outcropping. The drill hole at 4 reaches the oil sands at less depth than at 3 and 5. Simple as these cases may seem, it is

by no means unusual to see wells located on hill tops when they would have the advantage of accessibility and would be shallower when located in cañons or ravines. It is, of course, imprudent to select a site in the bottom of a gully where the torrents would be liable to wash away the rig, but place the rig on one side of the ravine, where it would be out of a torrent's path.

Erosion.—Erosion determines to a great degree the location of a test well. By erosion is meant the wearing down of the earth's surface due to the action of rivers, rains, winds, frost, and chemicals in the air. In some oil fields, deep cañons have been cut through the oil formations and have resulted in draining the

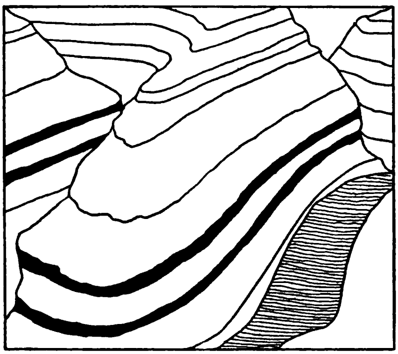


FIG. 59.—Shows how erosion exposes oil sands to drainage.

oil from the oil strata. The San Juan oil field of Utah is supposed to have been drained by the San Juan river that cuts a cañon through the anticline, exposing several oil strata. (See Fig. 59.) In locating wells in such a field drill down the dip from the exposed strata.[1]

Deformations.—FAULTS.—Under this heading we will consider sudden changes in dip due to faulting, and to minor folds. Perhaps no question dealing with locating involves more complexities than the problems of faulting. Faults are so irregular and numerous in some fields that they become important factors in choosing well sites. Fig. 29*a*, Chapter IV, shows a thrust fault

[1] Light gravity oils with a paraffine base may escape and leave the strata barren.

involved with folding. Such a sketch is valuable to the man who wants to know why oil is not found in certain localities. Wells at 1 would and did prove barren, while those toward the right were productive.

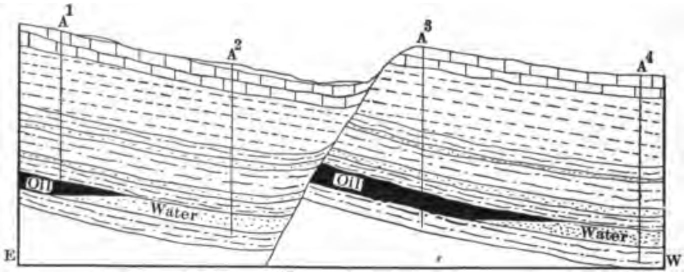


FIG. 60.—Illustrates how the upthrow side of a fault acts as an anticline; the downthrow side, as a syncline.

Again, in Fig. 60, there is a normal fault, showing the influence of such a fault on the oil strata. In this case the upthrow side of the fault on the west acts as an anticline, the down-

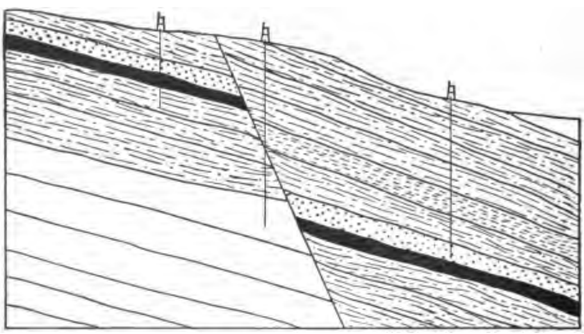


FIG. 61.—Illustrates how normal faulting may leave barren spaces.

throw side, as a syncline. Wells 1 and 3 obtained oil; 2 and 4 did not.

In Fig. 61 a fault is shown that illustrates how a drill hole might pass between productive oil strata and fail to strike oil

in commercial quantities. The shale on the hanging-wall side abuts against the oil sands on the footwall side, and confines the oil to the sands below.

Faults do not necessarily affect oil formations adversely, as shown in Figs. 27 and 29*b*, Chapter IV. Careful study will show that in many cases faults are beneficial rather than detrimental.

Minor Folds.—Minor folds have a very decided effect in some regions. Fig. 62 shows a number of minor folds on the flank of a monocline. These folds must be taken into consideration in drilling. Thus wells placed at various points, as at 1, 3, and 5, would strike oil and gas at much less depths than the major slope indicates. In such cases, too, one might strike water sands in the lower arches as at 2, 4, and 6 and consider the field

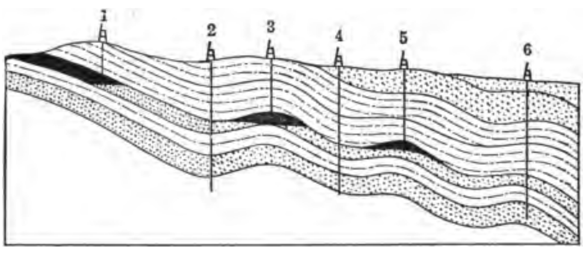


Fig. 62.—Shows lower fold non-productive; folds higher on slope increase in quantity of oil.

as barren. Such a conclusion would be wrong. A knowledge of such minor folds is of great importance in locating wells in all oil fields.

Twin Anticlines.—The two anticlines shown in Fig. 63 are really minor crumples on one big fold. However, one is apt to be greatly misled by the minor crumples. By placing a well at 1, the lower oil sand was missed entirely, while in a well at 2, the lower oil sand was reached at a moderate depth. The true apex of such a fold is at A, and the axis is inclined as shown. Broad flat-topped folds of this type are very deceptive.

Disappearing Folds.—In many cases, especially where soft shales, clays, sands, and gravel overlie harder beds, surface

folds disappear at shallow depths. The wrinkles on the surface die out as shown in Fig. 64. Where this is the case, no localization of the oil would take place at depth. Drilling for petroleum would not be advised under such conditions.

Joint Planes.—At Florence, Colorado, petroleum occurs along joint or small fault planes on a low westward dipping monocline. Wells drilled into the joint planes obtain oil, but if the wells miss a crevice, oil is not obtained in commercial quantities. If two wells strike the same joint plane, one well will generally affect the production of the other by lowering the gas pressure, or by decreasing the oil production. Locating in such cases is very difficult.

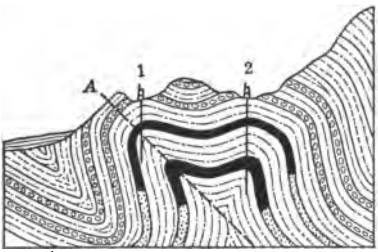


FIG. 63.—Illustrates well locations on minor folds of a highly compressed structure.

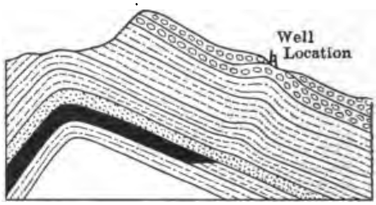


FIG. 64.—Illustrates a minor fold disappearing with depth.

Locating Wells on Domes.—On *anticlinal domes*, select the high points or crests of the domes on which to place the wells. Where such domes are unsaturated with water, oil will not occur on the apex but around it. Such unsaturated domes occur in some of the Pennsylvania and Wyoming fields.

With *volcanic necks*, the wells must be started to miss the volcanic rocks. (See Fig. 23, Chapter IV.)

With *saline domes*, the oil is found overlying the salt core and to the side of it in many cases. However, careful work is necessary to determine well locations in such fields, and often the only way is to drill and find out the underground conditions. It has been found that drilling in the center of these

domes generally lands the hole in a salt core instead of an oil-producing formation. The best practice is to locate the test holes on the slopes of the domes, several hundred feet from the center, thus missing the salt core. (See Fig. 24, Chapter IV.)

Wells under Ocean or Lake.—It has been often asked why oil should be found under the ocean. At Summerland, Santa Barbara county, California, a good illustration is found. Fig. 65 roughly illustrates the existing conditions. Wells are there located on piers extending into the ocean. In drilling, the ocean water is cased off, and drilling proceeds much as on dry land.

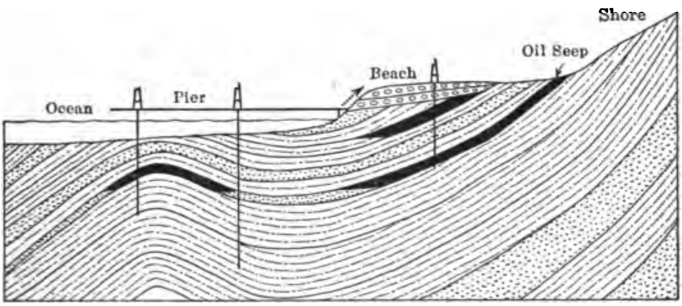


FIG. 65.—Illustrates oil out in ocean; derricks on piers.

Effects of Steep Dips (See Fig. 66).—Steep dips increase depths rapidly. Wells placed at 1 will strike the sand close to the surface, but at 3 and 4 will deepen rapidly. The productive area will here necessarily be narrow and confined to the crest of the anticline.

Types of such anticlines are found in the Olinda oil fields of California, the Los Angeles field, the Pico anticline of Los Angeles county, and the Modelo anticline of Ventura county, California.

In such anticlines, the apparent thickness of the oil sands is very great as the drill travels through the beds for a much greater distance than if the beds lay more nearly horizontal.

By drilling a short distance off the axis, one may easily miss the productive strata. (See 4, Fig. 66.)

Where steep-dipping oil-bearing formations occur uncovered (see Fig. 66), there is a better chance of the oil being retained than in strata where the dips are gentle. This is especially true in arid regions where the rainfall is small. The steeper the dip the less the chance of catching water, as the runoff is large and the surface exposed small.

Such highly compressed folds are often fractured and faulted along the line of the axis so that seepages are common; and oil may also find more porous reservoirs there.

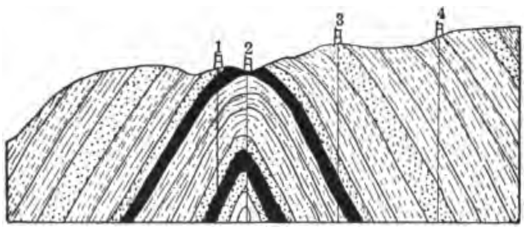


FIG. 66.—Illustrates locating of wells on steep dips.

Locating Wells on Terraces.—On terrace structure, the flat part of the structure carries the oil. To obtain the best results locate a well on the flat part of the structure away from the surface axis, as at 1 and 2. (See Fig. 20*a*.) (East of axis in this case.)

With a terrace the axis dips with depth, so the axis of the oil stratum will not lie immediately below the surface axis but at an angle to it. (See Fig. 20*a*.)

Locating Where Structural Features are not Evident.—We have so far considered locating where evidence of structural features are known. Where out-croppings are not in evidence drilling is necessarily an uncertain process. In such cases, one must be guided by local experience in drilling for water, by abandoned oil tests, by mine records (if any are available) and any evidence of "oil sign" that can be found. Necessarily one must be prepared

to drill to a considerable depth in such cases. No estimates of probable depth to reach oil are trustworthy here, and under such conditions a well is a gamble.

When capital is available, several drill holes may be put down; if the first one proves barren, the second may succeed. Indeed it is not unusual to find oil in regions that have been declared barren by earlier prospectors.

Só far, we have considered the factors involved in the location of oil-well sites. The next chapter will consider some of the factors in actual drilling operations.

CALCULATIONS FOR DEPTHS TO OIL SANDS

Method 1.—In Fig. 67 the elevation of the seepage above sea level is given as 1000 ft. and the elevation of the well site as 1425. The difference in elevations is $1425 - 1000 = 425$, or $bd = E$.

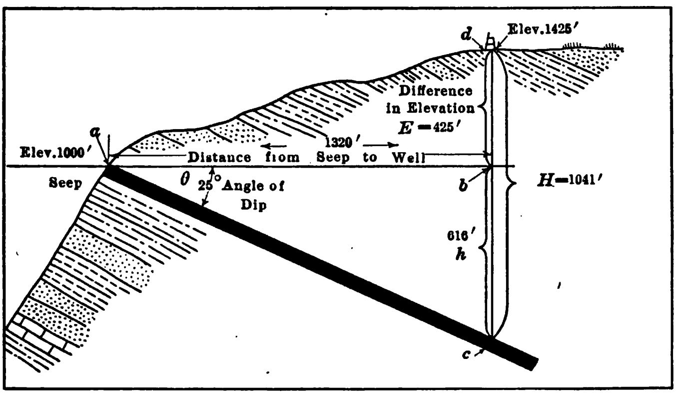


FIG. 67.—Method of estimating the dip of a bed.

The horizontal distance between the two points is ab, or here 1320 ft.

The angle of dip, θ, of the oil formation is 25°.

The height bc is desired.

To find the total depth H, add bc to E.

By Trigonometry:

Formula: $\tan \theta \times (ab) + E = H.$

$\tan 25° \times 1320 = bc.$

$\tan 25°$ (obtained from a log table) $= .4663.$

$.4663 \times 1320 = 616$ (approx.) $= bc.$

$H = 616 + 425 = 1041$ ft., the depth to the sand.

Such depths are approximate as one does not always know of changes in thickness of formations or in dips underground.

Table XI.—Depth to a Stratum Below the Horizontal Surface for Various Distances and Dips

(After Hayes)

Angle of dip	Feet						1/4 mile (1320 ft.)	1/2 mile (2640 ft.)	3/4 mile (3960 ft.)	1 mile (5280 ft.)
	100	200	300	400	500	1000				
1	1.75	3.50	5.25	7.00	8.75	17.5	23.04	46.08	69.12	92.16
2	3.49	6.98	10.47	13.96	17.45	34.9	46.09	92.18	138.3	184.4
3	5.24	10.48	15.72	20.96	26.20	52.4	69.18	138.4	207.5	276.7
4	6.99	13.98	20.97	27.96	34.95	69.9	92.30	184.6	276.9	369.2
5	8.75	17.50	26.25	35.00	43.75	87.5	115.5	230.5	346.5	461.9
6	10.51	21.02	31.53	42.04	52.55	105.1	138.7	277.4	416.1	555.0
7	12.28	24.56	36.84	49.12	61.40	122.8	162.1	324.2	486.3	648.3
8	14.05	28.10	42.15	56.20	70.20	140.5	185.5	371.0	556.5	742.0
9	15.84	31.68	47.52	63.36	79.20	158.4	209.1	418.2	627.3	836.3
10	17.63	35.26	52.89	70.52	88.15	176.3	232.8	465.6	698.4	931.0
11	19.44	38.88	58.32	77.76	97.20	194.4	256.6	513.2	769.8	1026.0
12	21.26	42.52	63.78	85.04	106.30	212.6	280.6	561.2	841.8	1123.0
13	23.09	46.18	69.27	92.36	115.45	230.9	304.7	609.4	914.1	1219.0
14	24.93	49.86	74.79	99.72	124.65	249.3	329.1	658.2	987.3	1316.0
15	26.80	53.60	80.40	107.20	134.00	268.0	353.7	707.4	1060.0	1415.0
16	28.68	57.36	86.04	114.72	143.40	286.8	378.5	757.0	1136.0	1514.0
17	30.57	61.14	91.71	122.28	152.85	305.7	403.6	807.2	1211.0	1614.0
18	32.49	64.98	97.47	129.96	162.45	324.9	428.9	857.8	1287.0	1716.0
19	34.43	68.86	103.29	137.72	172.15	344.3	454.3	908.6	1363.0	1817.0
20	36.40	72.80	109.20	145.60	182.00	364.0	480.4	960.8	1411.0	1923.0
21	38.39	76.78	115.17	153.56	191.95	383.9	506.7	1012.0	1520.0	2027.0
22	40.40	80.80	121.20	160.60	202.00	404.0	533.3	1067.0	1600.9	2133.0
23	42.45	84.90	127.35	169.80	212.25	424.5	560.3	1121.0	1681.0	2241.0
24	44.52	89.04	133.56	178.08	222.60	445.2	587.7	1175.9	1763.0	2351.0
25	46.63	93.26	139.89	186.52	233.15	466.3	615.5	1231.0	1847.0	2462.0
26	48.77	97.54	146.31	195.08	243.85	487.7	643.7	1287.0	1931.0	2575.0
27	50.95	101.90	152.85	203.80	254.75	509.5	672.6	1345.0	2018.0	2690.0
28	53.17	106.34	159.51	212.68	265.85	531.7	701.8	1404.0	2105.0	2807.0
29	55.43	110.86	166.29	221.72	277.15	554.3	731.7	1463.0	2195.0	2927.0
30	57.74	115.48	173.22	230.96	288.70	577.4	762.1	1524.0	2286.0	3048.0

Use of Table.—Table XI may be used in many cases to simplify calculations. Where the dips are given, it is a simple matter to use the table. In Fig. 47 the angle θ is 25°, and the distance is 1320 ft. or ¼ mile. From the table one finds the depths from the horizontal to be 615.5 ft. Add the difference in elevation, E, or 425 ft. to 615.5 ft.; then $615.5 + 425 = 1040.5$, or 1041 ft., approximately.

Method 2 (See Fig. 68).—The second method is the graphic method. By using cross-section paper one accurately lays out

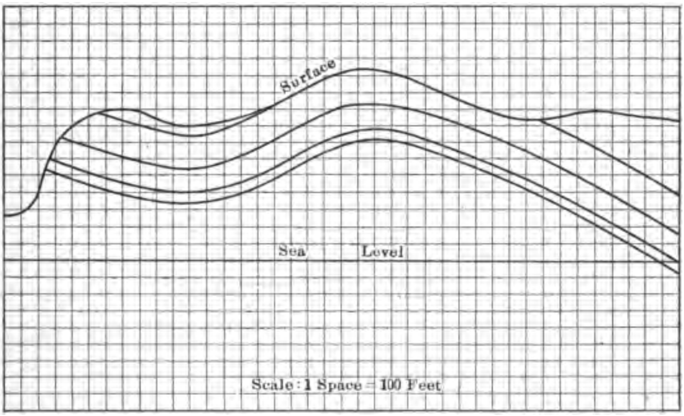


Fig. 68.—Graphic method of finding depth.

the surface and then the underground structure as closely as possible. By this method one can approximately determine the depths to certain formations and scale them off directly.

Where this method is employed the underground structure is clearly shown by cross-sections. Accurate depths are only possible where well logs are accessible, but very good approximations may be obtained by the graphic method. Many large oil companies use the graphic method of mapping their oil territory.

Method 3 (See Fig. 69).—Where no oil sands are in evidence and the anticline is closed, the only way to determine depths is

by means of some definite horizon. When this horizon is known either through fossils or lithologic evidence as explained under

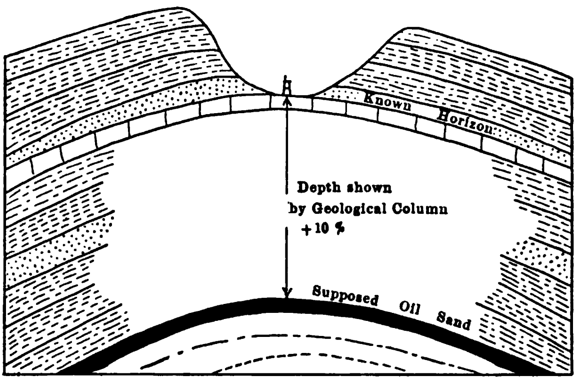


FIG. 69.—Illustrates use of geological column.

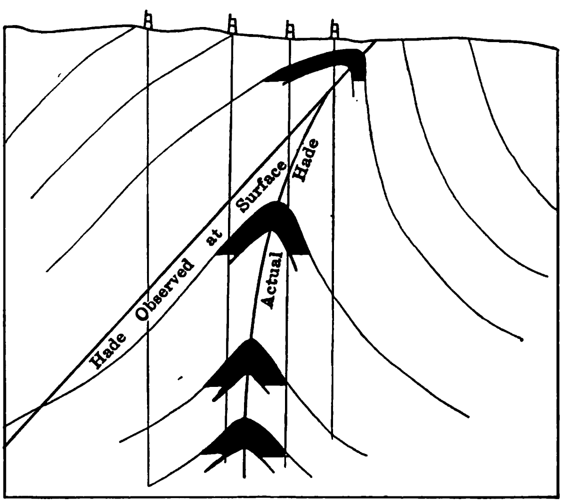


FIG. 70.—Shows curving of axis underground. (After Craig.)

Stratigraphy (Chapter II), the probable depth to oil is obtained by comparing the relations of the known horizon to the other

formations shown in the geological column. Suppose that a known horizon is found and oil should supposedly occur below at a certain depth, then add the depth, taken from the geological column, to the depth of the known horizon. By such a method, the depth to oil may often be approximately determined.

Curved Axes.—In some cases the axes of anticlines show a tendency to overturn and to shift at the top. As shown in Fig. 70, the axis of the fold describes a curve. Where such is the case, the hade or slope of the axis at the surface, represented by the straight line, would be misleading. The true condition is the curved line. Such curved axes are often found in folds with sharp crests. Calculations such as the preceding may then be misleading.

CHAPTER VII

FACTORS IN OIL-WELL DRILLING

Choosing a Rig.—When a site has been selected it is necessary to choose the proper kind of rig for testing. Portable rigs or permanent rigs may be used. If it is desired to drill a series of holes from 300 to 1000 ft. deep, a portable rig capable of drilling 1200 or 1500 ft. may be employed for this purpose. Such rigs (see Fig. 71) are capable of excellent work up to 1000 ft. They are admirably adapted for regions where the formations require little or no casing to keep the drill holes in shape. However, when it becomes necessary to handle several "strings" of casing, permanent rigs are much more desirable than portable. The portability of a rig is only one feature of rig selection and has to do chiefly with the convenience of moving a drilling machine. The system of drilling most favorable to meet local geological conditions must be selected. There are three principal systems employed in field work: (*A*) Standard cable-tool system (see Fig. 72); (*B*) hydraulic rotary system (see Fig. 73), and (*C*) combination of *A* and *B*.

The choice of one of these systems depends principally upon geological factors. A discussion of these factors and their effects upon the drilling of holes gives a key to the selection of the rig. As nearly all oil men are familiar with the various drilling systems, descriptions of the same will be passed over here.

The standard cable-tool system is perhaps the most generally used and most popular system at present. An addition, or, rather, an improvement to this system consists in what is called the "circulator method." In this method standard cable-tools are employed while water is caused to circulate through a casing as with the hydraulic-rotary system.

In drilling an oil well the four chief objects in view are: (1)

To find commercially valuable deposits; (2) to drill a favorable sized hole for obtaining and maintaining a good production;

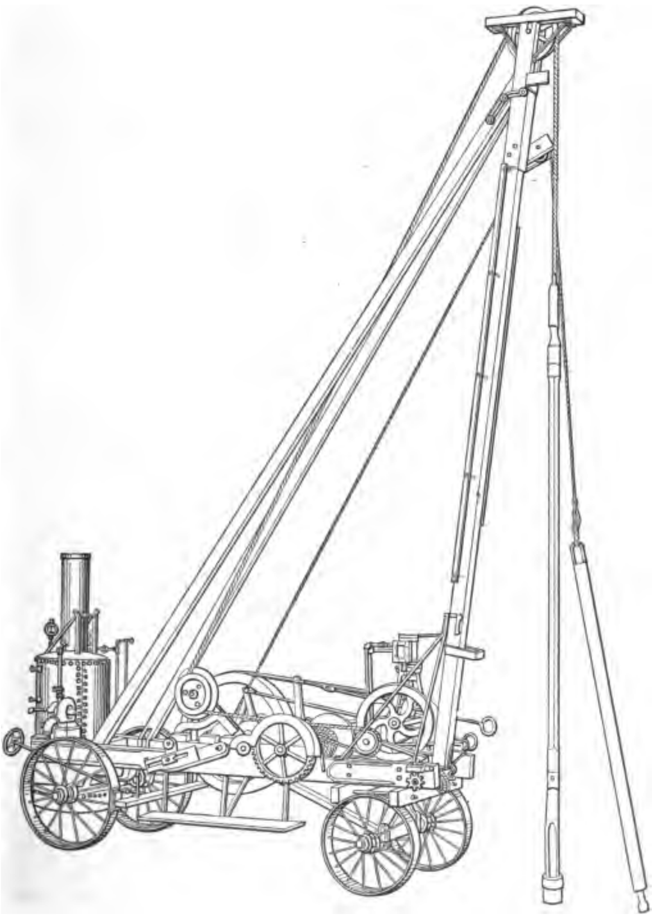


FIG. 71.—Portable drilling rig.

(3) to drill in as short a time as possible; and (4) to exclude all water from the oil sands.

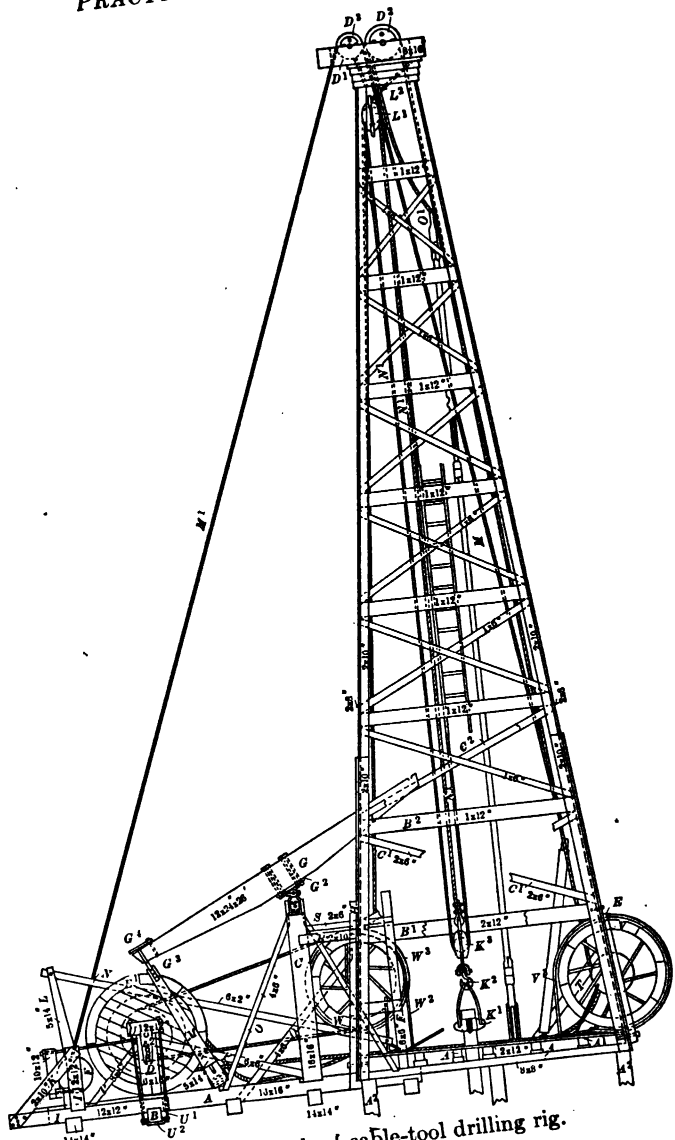


FIG. 72.—Standard cable-tool drilling rig.

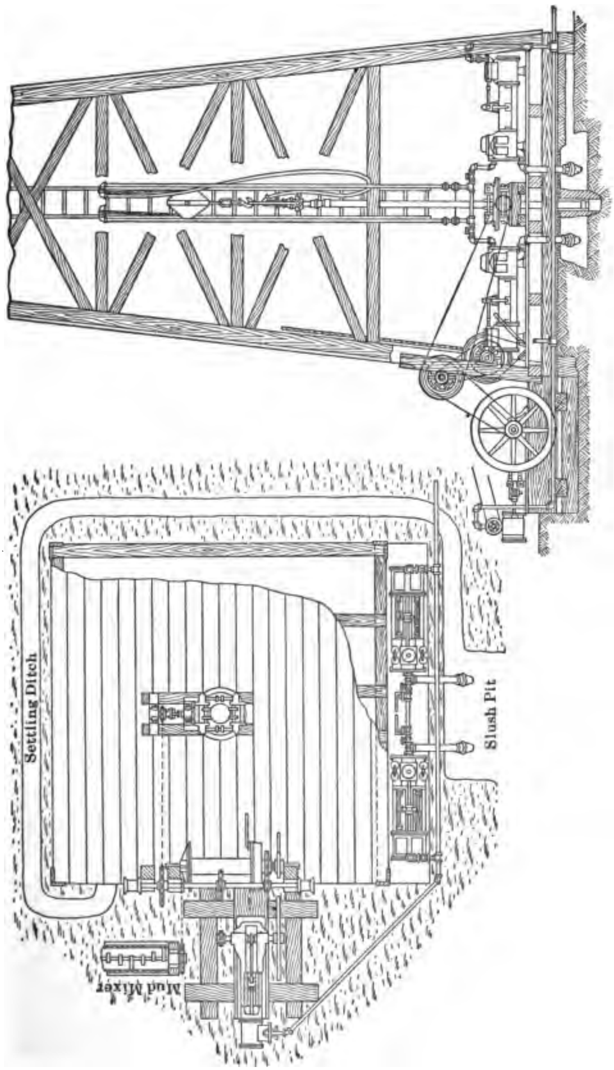


FIG. 73.—Hydraulic rotary drilling rig. (After U. S. G. S.)

(1) Locating has to deal with the probabilities of finding oil, and was discussed at length in Chapter VI.

(2) Favorable Size Holes—(Casing).—The following discussion of favorable sized hole applies more specifically to wells in new or "wildcat" districts. After the first wells have been drilled, it may be and often is found that it is possible to dispense with one or more strings of casing in drilling later wells, or start with holes of smaller diameter. It is generally considered desirable to finish a hole with a casing, diameter not under 4½ in., better sizes being 6¼ to 8¼ in. To obtain a 400-ft. hole with a diameter of 6¼ in., one would proceed as follows: To allow for probable water sands, trouble with the upper casing, and accidents, it is advisable to start with the top diameter of 10 in. This permits the use of 8¼-in. casing inside the 10 in., 6¼-in. inside the 8¼-in., and then 4½-in. inside the 6¼-in. In many cases it will be possible to finish a hole to this depth with one or two strings of casing, 10 and 8¼-in. sizes. The two extra sizes, 6¼ and 4½ in., allow for unusual trouble.

A standard cable-tool hole 2500 ft. to 4500 ft. in depth would be started with 16-in. or even 18-in. casing. This would allow a 12½-in. inside the 16-in., 10-in. inside the 12½-in., 8¼-in. inside the 10-in., 6¼-in. inside the 8¼-in., and 4½-in. inside the 6¼-in. Even then, 3-in. casing might be used inside the 4½-in. Such an unusual amount of casing is seldom used, as holes are generally finished with 8¼ or 6¼-in. sizes when starting with the 16-in. hole. The casing noted above is necessary with the standard cable system of drilling in California.

In Oklahoma, Kansas, Illinois, and the Eastern oil fields, drilling practice varies from this considerably. On the whole, however, the formations are older and more consolidated, hence "stand up" better or do not cave so readily, though in certain of the Oklahoma oil fields, especially Blackwell in Kay County, and Healdton in Carter County, conditions approximating California conditions occur. Also the sand conditions are well understood. It is generally only necessary to shut off the water sands from the oil sands; though in some cases, gas sands must be conserved.

It is the rule to use a conductor to shut off surface for water, and then drill until a water sand is encountered. In drilling "dry" (*i.e.*, without any water except that put in from the top) as a rule the water sand is cased off, the hole is then reduced and carried to the oil sand. If a second sand is encountered the same procedure is followed or the hole is underreamed and the casing loosed from its first position and set lower, if the distance is not too great. Where but one water sand is encountered, wells 1200–1500 ft. deep are started with a 10-in. conductor and finished with a 6¼-in. hole, having only one string of 8¼-in. casing in the hole to shut off water, and from 10 to 20 ft. of 10 in. casing as conductor.

In rotary drilling the two holes described above would be finished as follows: The 400-ft. hole would have two strings of casing, one 10 in. in diameter, the other 8¼ in.; 2500-ft. holes would be finished with two strings of casing, one 12½ in. in diameter, the other 8¼ in., or even 10 in., though in some unusual cases three or four strings might be required.

The principal factors involved in the above selection of casing are, namely, water sands and quicksands. In both systems of drilling it is necessary to make sure that all water is kept from entering the oil sands from any formation lying above the sand.

In some cases one may prospect below a proven oil sand and encounter a lower water sand, and then below that several oil sands. It then becomes desirable to use an extra string of casing to shut off the water between the oil strata, though not absolutely necessary if there is little water below.

In rotary drilling, the drill hole is kept full of circulating water. Quicksands are easily penetrated by this method as the head of the water in the hole keeps the sand from coming into the hole too freely. With standard cable-tools, however, quicksands or loose, friable sands of any kind become a source of trouble, and require "casing off." Where quicksands are present the standard hole would require at least one more string of casing than by using the rotary system. However, where the circulator method

is employed the rotary system has no advantage over the standard tools as to the amount of casing. Water sands and quicksands must be considered in another light. Even when they do not affect drilling they may, later, when under considerable head, collapse the casing and destroy the hole. This becomes a distinct evil and causes a great deal of trouble and expense. To overcome these pressures extra heavy casings must be used. We have now considered the principal requirements of casing as affected by geological factors. Discussion of the above requirements apply where drilling is carried on in soft formations. Where limestones or sandstones are the predominant features, there is little need for casing except to hold back water or prevent the escape of oil into dry sands.

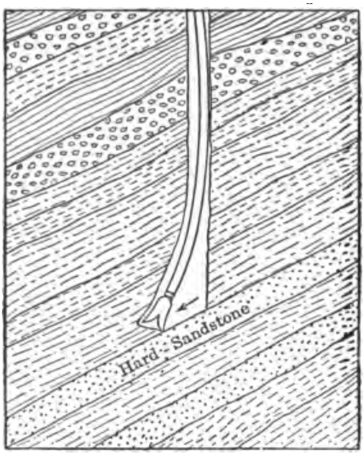


Fig. 74.—Rotary bit following hard stratum.

Crooked Holes.—Another requirement for favorable holes is that they be straight. Crooked holes cause unnecessary expense, and later cause great wear and tear in the producing well. Sometimes crooked holes seriously interfere with the entrance of casing. This results in loss of time and sometimes loss of part of the casing. The principal cause of crooked holes is the striking of hard strata that have steep dips. Suppose one is drilling in clay or shale, and that the drill suddenly strikes a hard stratum of sandstone. (See Fig. 74.) If the drill is allowed to proceed rapidly, it will follow down the hard stratum until the drill-stem strikes the opposite wall of the hole. The longer the drill-stem the less the deflection. If drilling proceeds slowly a straight hole will result without much extra trouble or loss of time.

With the rotary system the deflection of the drill is limited by the elasticity of the drill rod and when the same is bent to strike the opposite wall, the drill will proceed through the hard formation. Slow, careful drilling will also, in this case, give a straight hole. When drilling through steep beds, it is a wise precaution to proceed slowly when a hard stratum is encountered. Knowledge of such a stratum is quickly ascertained by any competent driller who instinctively learns to recognize the difference of strata by the way in which the blow of the drill is transmitted through the drilling line. A good driller can almost immediately tell by the stroke of the tools when the drilling bit has encountered a hard stratum.

(3) Time of Drilling.—The factors immediately effective in speed of drilling are:

(1) Depth, (2) diameter of hole desired, (3) water sands, (4) quicksands, (5) dry sands, (6) hardness of strata, (7) boulders, and (8) cavities.

Necessarily the length of time taken to lower and raise the tools increases directly with the depth. Also to handle long strings of casing more effectively and quickly, it becomes necessary as a time-saving element to erect high derricks in which three or four lengths of casing, each length being 20 to 22 ft. over all, can be stood in the derrick without trouble.

Such stands are from 60 to 80 ft. in length. To pull these stands, it is necessary to have derricks that are from 82 ft. to 120 ft. in height. High derricks are èmployed in holes over 1500 ft. in depth. The following figures will give some idea of the heights of derricks used for varying depths. For shallow holes, 400 to 600 ft., where the casing may be rapidly handled, 64-ft. frame derricks would be used. Up to 1500 ft., a 72-ft. derrick would be used; up to 3000 ft., an 82 to 90-ft. derrick and beyond that depth, 106 to 120-ft. In rotary drilling, 82 to 120-ft. derricks are used, the 82-ft. being used up to 2000 ft., and higher derricks above that depth.

The length of cable is also directly affected by depth. The greater the depth, the longer the cable becomes and the larger its diameter within certain limits.

The size of drilling cables varies with the diameter of the hole and the depth. For deep holes, 2000 to 3500 ft., with large diameters, 8¼ to 6¼-in. casings, cables 1 to 1¼ in. in diameter are used. For holes up to 2000 ft., ¾ to ⅞-in. lines are used. Deep holes 3 in. in diameter can effectively use ¾-in. lines.

In drilling with a standard rig the best speed is made in a dry hole. In oil-field phraseology a "dry hole" is one in which water must be put in the hole to thin the drill cuttings, to keep the bit from overheating, and to soften the formation. When a water sand is encountered, the hole becomes a "wet" one, that is, furnishes water enough to meet the needs of drilling. In "dry" holes it is only necessary to keep a small quantity of water in the hole; "wet" holes are nearly full and the surplus water retards the stroke of the tools and weakens their impact, resulting in slower drilling.

In many fields Manila cables are used until water is struck, and from there on steel cables are employed. In "wet" holes water retards the speed of drilling to such an extent that it becomes necessary either to case off the water sands or use wire cables. Wire ropes or cables are commonly employed with standard cable-tools for deep drilling, 2000 ft. or more. With the hydraulic-rotary system, however, water does not retard the speed of drilling; indeed the extra water saves the introduction of water from the surface, and thus becomes an important factor in economical drilling. Where, however, the flow of water is very strong, the rotary mud is washed from the hole and slow progress results.

Where the head of water in the bore hole is greater than that in the water sands, circulation is affected, and the water instead of returning to the surface enters the water sand. To overcome this trouble, it is necessary to pump mud into the hole. This mud fills the interstices of the sand and keeps the water from escaping from the bore hole.

Dry sands are pernicious in both systems of drilling. These Sands absorb water and cause an undue quantity to be pumped into the hole, since without water the bits would soon overheat,

and the cuttings would accumulate to such an extent that they would retard the action of the drill. By introducing mud into the hole the walls of the dry sands are puddled and the water held in the hole. It is often necessary to put in many tons of mud which is mixed in sump holes at the surface. This mud has the consistency of thick cream and is either poured or pumped into the hole.

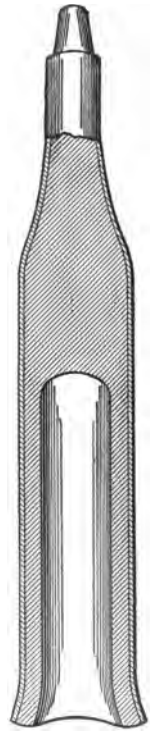


FIG. 75.—Standard cable-tool drill-bit.

Hardness of Strata and Its Effect upon Drilling Operations.—1. SANDS.—Drilling in sands is generally fast work, especially where the rotary or "circulator" systems are employed. Standard cable-tools penetrate sands rapidly though the bits are worn quickly by the sharp sand grains. Where the sands have a tendency to shift or cave, standard cable-tools have a hard time to "make hole." In such cases, days are sometimes required to drill even a few feet. Under such conditions, rotary sand circulators do the best work. With them it is possible to drill from 100 to 200 ft. per 24 hours in sandy strata.

2. SANDSTONES.—Hard sandstones and limestones are quickly shattered by the heavy blows of the standard cable-tools. The heavy standard bit (see Fig. 75) makes good progress in such formations, though the wear and tear on the bits is fairly great. In rotary drilling, however, especially where a fish-tail bit (see Fig. 76) is employed, little headway is made, and in such cases another form of bit must be employed, either a core barrel, adamantine with a reversed fish-tail bit, a rotary shoe with adamantine or the Sharp & Hughes bit. (See Fig. 77.)

In the writer's estimation, the early lack of success of the rotary system of California was due most of all to the drilling of the shell or sandstone formations with fish-tail bits. Only a

few satisfactory holes had been put down with a rotary and these required a longer time than seemed necessary. The fish-tail bit was almost invariably employed in drilling through all formations; though at present it excels for drilling in soft materials, its use is deprecated in hard formations.

Another trouble with sandstones, especially where a string of casing is carried close to the bottom of the hole, lies in the fact that the drill which fits snugly inside the casing does not make a large enough hole in the sandstone to allow the casing

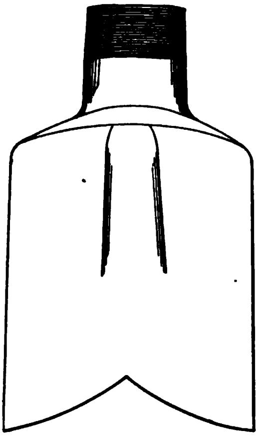


Fig. 76.—Fish-tail rotary bit.

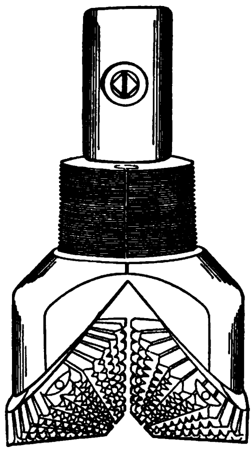


Fig. 77.—Sharp & Hughes hard rock rotary bit.

Fig. 78.—Underreamer.

to go through it. To meet this objection, underreamers are used. These underreamers (see Fig. 78) are really expansion bits. When let down through the casing, these bits project beyond the casing shoe and enlarge the diameter of the hole so that the casing can be forced downward.

3. Clays and Shales.—In drilling through clays and shale with standard cable tools, the greatest difficulty encountered is the tendency of the clay to stick to the bit. This tendency makes drilling in the soft clay a slow process. There is also the tendency of the clay to "creep" or to cave into the hole. This

tendency may be overcome to some extent by keeping the hole full of water, and by carrying the casing close to the drill. The hydraulic-rotary system and the "circulator" method are well adapted for drilling through clay and shale. By these methods one literally washes out the soft material and can make very rapid progress, in exceptional cases from 200 to 300 ft. having been made in 24 hours. Clay does not dull bits rapidly so that when drilling in it there is little need to draw the tools from the hole to sharpen them.

4. Boulders.—Boulders are a source of trouble wherever found. They may occur as concretions in sands and shales, or as conglomerate beds made up of material ranging in size from that of an egg to the size of one's head and larger.

Concretions are encountered in many regions and explain the presence of unusually hard streaks in what would otherwise be solid beds of shale and sand. Concretions are harder than the surrounding material and thus check the speed of drilling somewhat. In a few cases, however, large boulders may be mistaken for solid beds of sandstones and casing landed on them.

Where the boulders consist of material different from the immediate formation, one is warned against landing the casing on them. The greatest trouble with boulders, however, comes from the boulder beds. When a drill has passed through such beds there is always a liability that a boulder may fall in above the drill-bit and wedge if fast. Especially is this the case in rotary drilling where a fish-tail bit is used. In this case the boulders lodge above the bit between the drill rods and the wall of the hole and wedge the bit tight. Many hoes are thus lost. It is sometimes possible to unscrew the rotary pipe and later drill up the rotary bit or sidetrack the same, if the walls of the hole are of clay or shale. Where, however, the walls are sandstone or limestone, sidetracking is out of the question. In some cases it is possible to break up the boulders by letting down a string of light cable tools alongside the rotary pipe.

One ingenious operator in a case where the driller could neither drill nor pull the pipe, devised a method that proved effectual.

Oil sand was expected within a few feet. To abandon the hole meant a heavy monetary loss. As the drill pipe was 4½ in. in diameter the operator determined to drill through the rotary bit below by using a steel bit harder than the rotary bit. Using 2-in. drill rods he milled through the rotary bit below and reached oil sand, obtaining a good flow of oil through a 2-in. hole.

5. Cavities.—Cavities are very uncertain factors in oil well drilling. They may be classified as follows:

(1) Those along fault or fracture planes; (2) solution cavities; and (3) "washout" cavities.

In some regions like Boulder, Colo., cavities have been reported in drill holes. They are supposed to be in fracture plane. In these regions the drill tools drop suddenly into underground fractures or crevices due either to faulting or folding. Such cases are assumptive and explain the unusual phenomena better than anything else.

In limestone regions solution cavities are plentiful. Indeed, great underground caverns are of frequent occurrence. In such regions the disappearance of water in a drill hole and the sudden dropping of tools is in no way a mystery, but rather to be expected at any time.

"Washout" cavities are purely artificial and are due to the withdrawal of soft sand or shale from under a hard stratum of sandstone or limestone.

In drilling, the softer sand may cave and cause a cavity to form below a hard stratum. If a hydraulic rotary be used, great quantities of sand may be washed from the hole. Where the sand begins to wash out, especially where there is any tendency to shift, a sudden rush of sand may collapse the casing or perhaps cover up the drill tools, causing a difficult fishing job. In one instance a cavity of this kind was large enough to hold seven or eight wagon loads of boulders and brickbats, and over 2000 ft. of old bull-rope and Manila line was required before the cavity could be filled enough to form a bridge, upon which it was desired to rest a string of casing.

Rock Pressure.—Drillers and operators often speak of "rock

pressure" as the cause of gas pressure. However, the writer presents another aspect of rock pressure and its practical application to caving and heaving troubles—also the collapsing of casing which is notably the trouble in California, where the sediments are not as compact as in Pennsylvania and the Mid-Continent.

Compression Due to Rock Pressure.—Where the earth's strata are thrown into folds, these folds are under compression due to gravitative influence or due to the weight of the overlying formations. Some strata can resist less than others and are more subject to movements than others. Thus soft sands and shales are more subject to change due to compressive action than are sandstones and limestones. Shales and sands creep, shift or heave under compressive power that would not noticeably affect the harder formations.

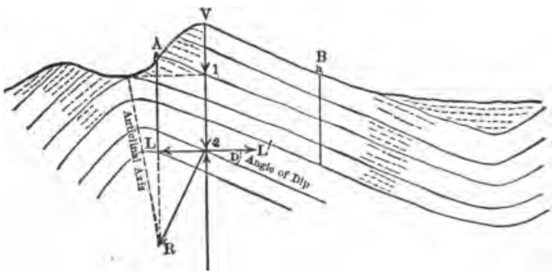


FIG. 79.—Illustrates direction of resultant L, which tends to collapse casing.

Folds furnish excellent conditions for unbalanced pressures and consequently, when drill holes which disturb the equilibrium of a series of pressures are put down, collapsing of the casing or caving of the open hole results.

Consider the fold shown in Fig. 79. At any point the vertical pressure of the strata may be resolved into a component at right angles to the dip of the strata. This component R can be resolved into a resultant L, which we will call the lateral pressure. It is the action of this lateral pressure which the writer believes explains casing troubles more fully than any other theory. The

resultant toward the syncline compresses casing in holes which are drilled down the dip from the outcroppings of oil strata.

By trigonometry the resultant compressive power L is given by the following expression:

L = cos angle of dip $\times$ cos 90 $-$ angle of dip W.
(W is the weight of overlying strata.)

Theoretically this pressure is greatest when the angle of dip is 45°, decreasing when the angle decreases or increases above 45°.

Measure of Pressure.—Suppose a thickness of strata of 3000 ft. composed of clays, shales, conglomerates, sands, and sandstones. The average specific gravity of such strata is 2.5. That is, 1 cu. ft. of such material weighs 2½ times the weight of a cubic foot of water under atmospheric pressure and at 60°F.

Water weighs 62.5 lb. per cu. ft. Then 1 cu. ft. of the above materials will weigh $62.5 \times 2.5 = 156 +$ lb.

A column of stone 1 ft. high and 1 sq. in. at the base will exert a pressure $\frac{156}{144} = 1.08$ lb. per sq. in.

A column of strata 3000 ft. thick will exert a pressure of $1.08 \times 3000 = 3240$ lb. per sq. in.

The lateral resultant of this for an angle of dip of 45° will be $L = \cos 45 \times (\cos 90 - 45) \times 3240$; or $0.5 \times 3240 = 1620$.

For an angle of dip of 30°$L = \cos 30 + \cos \frac{(90 - 30)}{60} \times 3240 = 0.866 \times 0.5 \times 3240 = 1403$.

Likewise for 60° dip $L = \cos 60 \times \cos \frac{(90 - 60)}{60} \times 3240 = 0.5 \times 0.866 \times 3240 = 1403$.

Such high pressures are certainly great enough to cause casing collapses in weak or defective casings. Even at a few hundred feet, pressures of 300 to 400 lb. may cause the formations to cave or to creep into the drill hole.

The deeper the hole is carried, the greater the pressures, and the greater the need for heavy casing. Table XII gives some casings tests. Note that the larger the casing and the less the weight, the

less resistance it offers to compression. In all engineering work it is usual to use factors of safety to insure sufficient strength to make up for any weakness in iron, steel, stone, or other materials due to flaws in the material. Such factors in oil-field work are 2 and 3. A factor of safety of 2 means that a casing has twice the resistive strength necessary to offset collapsing pressures. A 12½-in. casing weighing 40 lb. per ft. would withstand but 402 lb. lateral compression.

TABLE XII.—SHOWING COLLAPSING PRESSURES OR LAP-WELDED STEEL CASING FOR SIZES COMMONLY USED IN CALIFORNIA

Size, in.	Weight per ft., lb.	Inside diameter, in.	Outside diameter, in.	Thickness, in.	Collapsing pressure, lb. per sq. in.	Equivalent water column, ft.	Water column, factor of safety 2, ft.
4½	15.0	4.500	5.000	0.250	2944	6790	3395
5⅝	20.0	5.370	6.000	0.315	3160	7280	3640
6¼	20.0	6.000	6.625	0.312	2704	6230	3115
	26.0	5.845	6.625	0.390	3717	8560	4280
	28.0	5.775	6.625	0.425	4167	9600	4800
6⅝	20.0	6.437	7.000	0.281	2096	4830	2415
	26.0	6.312	7.000	0.344	2867	6600	3300
	28.0	6.220	7.000	0.390	3440	7930	3965
7⅝	26.0	7.390	8.000	0.305	1914	4410	2205
8¼	28.0	8.015	8.625	0.305	1680	3870	1935
	32.0	7.935	8.625	0.345	2080	4790	2395
	36.0	7.875	8.625	0.375	2383	5490	2745
	38.0	7.765	8.825	0.430	2928	6750	3375
	43.0	7.625	8.625	0.500	3638	8380	4190
9⅝	33.0	9.500	10.000	0.250	780	1800	900
10	40.0	10.000	10.750	0.375	1638	3770	1885
	48.0	9.850	10.750	0.450	2234	5150	2575
	54.0	9.750	10.750	0.500	2643	6090	3045
11⅝	40.0	11.437	12.000	0.281	641	1475	737
12½	40.0	12.500	13.000	0.250	402	927	463
	45.0	12.360	13.000	0.320	745	1717	858
	50.0	12.250	13.000	0.375	1109	2560	1280
13½	50.0	13.250	14.000	0.375	936	2160	1080
15½	51.3	15.416	16.000	0.292	314	724	362

However, a weak place in the casing might fall below that limit to one-half of the normal strength. Then if pressures of 300 to 500 lb. are exerted, the casing may collapse. The remedy here is simply to use a casing sufficiently heavy to have a factor of safety of 2 or 3 if possible and to use only good casing.

An $8\frac{1}{4}$-in. 28-lb. casing has a collapsing pressure of 1680 lb. A lateral rock pressure of 1000 lb. may readily be obtained at a depth of 2000 to 2500 ft. The factor of safety here is but 1.68, so that any weakness in pipe would lower the compressive resistance to a very dangerous point.

So far nothing has been said about drilling water in a test hole or oil in a pumping well. Of course where the hole is full of water, each 1000 ft. of water exerts a pressure of 434 lb. per sq. in. inside the casing. This pressure will help to balance the lateral rock pressure. Where, however, the well is bailed or pumped down, danger threatens.

Shooting Wells.—It is common practice in the Pennsylvania and the Mid-Continent oil-fields to shoot or dynamite the wells after they have been drilled into the oil stratum. This is done to break up the formation so it will form a reservoir for oil, and also cause channels to form in the shattered rock. Where the formations are hard sandstone, limestone, or very hard shale, shooting will break up the material sufficiently to form good reservoirs and channels; where the sands are soft and flowing, as in some of the Californian and Russian fields, dynamiting has no effect. Where soft shale makes up the oil stratum, the tendency is to compress or tighten the shales, thus keeping back the oil, instead of allowing it to enter the well.

In some instances especially where the sandstone is hard and compact, too heavy a shooting charge of nitroglycerin is used, and as a result the sandstone is pulverized instead of being made more coarse. The pulverized material cannot be entirely cleaned out, and is liable to clog the pores of the sandstones and keep back production.

Drilling through Coal Beds.—In certain parts of Pennsylvania and Illinois, workable coal beds are found above the petroleum

formations. Drill holes pass through these coal beds before entering the oil sands. Where the coal beds are worked there is danger of injuring the oil wells, also danger of accidents in the mine, due to escaping gas and injury from drilling accidents.

A knowledge of such beds is essential before commencing work, as the coal-mine owners must allow pillars of sufficient size to protect the oil well. The United States Bureau of Mines is doing excellent work along this line in Pennsylvania.

Logs.—(Records).—The value of logs in drilling must not be underestimated. Every company should keep a close accurate log of the formations through which the well or wells are drilled. Many thousands of dollars are annually lost through not knowing the location of water or of oil sands.

When casing troubles are at hand in oil wells, it is extremely valuable to know the location of important sands to intelligently redrill the well. The knowledge of certain formations in a new well enables an operator to proceed much more rapidly with the holes that follow. Contractors especially find such information very valuable.

By far too little attention is paid to logs. Some uniform system of keeping logs should be in vogue. Also every oil man should clearly understand the meaning of the various terms, clay, shale, gravel, etc. One driller calls a brown shale blue, or a blue shale brown, when others call it blue. This is a needless classification. Blue and brown are entirely different colors, but drillers sometimes classify these formations alike. Then, too, a sand and a sandstone are very different, as also are sand, and shale. Sand is very gritty; shale is softer and less gritty. Clay sticks to a bit and unlike shale has no small seams or layers in it.

One point on which the drillers make mistakes is in classifying the material while wet. Gray material when wet is blue, and brown and bluish shales when wet are nearly black. By letting the material dry, the true color will appear. If one driller classifies while the material is dry and the other while the material is wet, conflicts will arise.

Geologists generally differ little in their classification of sands

and shales. If drillers and superintendents would only follow the geologist's classifications, logs would be much simplified. Anyone who has attempted redrilling on a well where a number of drillers have worked will realize the utter folly of allowing half a dozen different classifications.

If the logs are worth keeping, and they are without doubt invaluable, keep them so carefully that no one can mistake

DAILY TOUR REPORT

Company	Lease	Well No	Day	Date	Tour
					Morning
					Afternoon

Formations

Depth		Formation	Color	Texture			Hardness			Contents										Remarks
										Water					Gas		Oil			
From	To			Coarse	Medium	Fine	Hard	Medium	Soft	Dry	Sweet	Salty	Sulfur	Barrels	Gas	Barrels	Poor	Medium	Rich	

Casing						Time			
Last Casing Put in Hole			Casing now used		Remarks	Driller	Hours	Tool Dressers	Hours
Size	Depth From	Depth To	Size	Depth					

FIG. 80.—Log form. (After Phelps.)

their meaning. How many oil men today can feel certain that the logs are carefully kept? "Wild-cat" drillers are often criminal in their negligence and later, when exact information is desired, none is available.

Any careful classification will do as long as it is adhered to. A form for keeping logs is given above. (See Fig. 80.)

WELL LOGS AND THEIR INTERPRETATION

In the hurry and bustle of their oil-field work, the operators too often fail to take time to study their well logs, with the results

that they obtain only part of the benefit that they might otherwise obtain.

The following discussion is presented to indicate a few points that have an important bearing on oil problems, but which, too

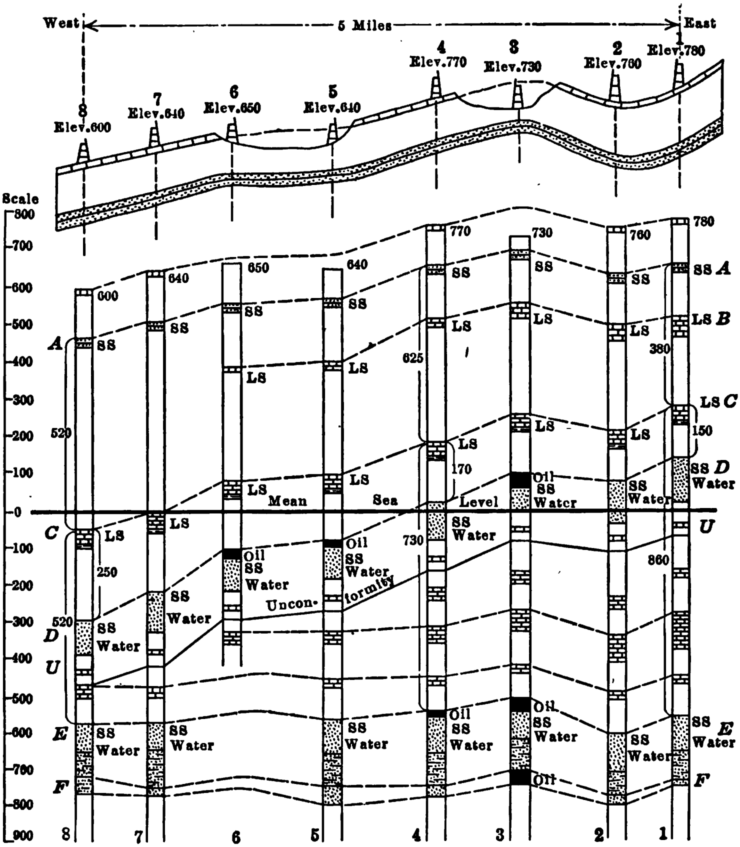


FIG. 81.—Interpretation of well logs.

often, are overlooked.

Fig. 81 is purely diagrammatic, presenting, however, condi-

tions known to occur in several fields. At the top of the figure the surface relation of the wells are given, also the surface appearance of the rocks.

The wells are numbered 1 to 8 across a distance of 5 miles. The elevations above sea level, obtained by a survey, are also given. Below the wells are skeleton or partial logs which are placed in their proper relation to sea level. The logs are all on the same scale.

Considering *C* as the key horizon, or base bed, the other beds *A*, *B*, *D*, and *E* are related to it. The interval between the tops of the various beds and their relations to the top of Bed *C* are found from the well logs. For example, at the top of *A* is 380 ft. above *C*, the top of *D*, 150 ft. below *C*, and the top of *E*, 860 ft. below the top of *C*.

With these points clearly in mind we can discuss the findings from the well logs.

The importance of well-kept records must not be underestimated, as accurate conclusions cannot be obtained upon inaccurate data.

The following structural conditions are shown in the diagram:

1. A synclinal condition occurs near 2, as the beds at 2 are lower than at 1 and 3. A faulted condition might exist, but such a fault would act as syncline; for all practical purposes the result would be the same.

2. An anticlinal condition occurs near 3 and between 2 and 4. Hole 3 shows the beds higher than at 2 and 4, indicating an anticlinal condition.

3. A terrace occurs at 5 and 6. The holes at 5 and 6 show a flattening of the dip giving a terrace condition there.

4. The average surface dip to the west is 36 ft. per mile. This dip to the west is obtained by subtracting the difference in elevations between two points and dividing by the miles.

The dip between 1 and 8, taken on the limestone shown at the surface is $(780 - 600) \div 5 = 36$ ft.

Again, the underground dip on *C* shows as follows: The elevation of *C* above sea level at 1 is 280 ft.; at 8 it is -50, or 50

ft. below sea level, or a total difference of 330 ft., between the two points. The dip of the bed is then $330 \div 5 = 66$ ft. per mile.

5. The dip is not constant, but varies from point to point. As is apparent, the dip from 8 to 6 is greater than at 6 to 5, or 4 to 2.

6. The limestone *B* decreases in thickness to the West and disappears. At 1 the limestone is thickest; at 7 it disappears.

7. The intervals between *A* and *C*, and *C* and *D* increase westward. At 1 the interval between *A* and *C* is 380 ft.; at 8 the interval is 520, a thickening of $520 - 380$ or 140 ft., in 5 miles, or 28 ft. per mile. The interval between *C* and *D* at 1 is 100 ft. in 5 miles or 20 ft. per mile.

8. The interval between *C* and *E* increases eastward showing an unconformity. The interval between *C* and *E* is 520 ft. at 8, and 860 at 1, a difference of $860 - 520 = 340$, or a thickening of 68 ft. per mile, east. Also the beds appear above *E* at 1, 2, 3, 4 and 5 that do not appear at 8. An angular unconformity is plainly apparent.

Note also that the underground folded structure at 6 and 3 is still strongly pronounced.

9. The beds are in themselves variable, as is illustrated in *F*. At 1, the sand is thin and increasing in thickness to 3, thinning at 4, and thickening at 5 to thin again at 7.

10. The well at 6 was not drilled to the deeper sands at *E* and *F*. However, at 3, the deeper sands have proven productive. Also, the shallow sand at 6 has production, and it is likely that the deeper sands at 6 will also prove productive, as there is a well defined folded condition at that point, which is favorable for an oil accumulation.

11. Needless to say the wells in the upper sand rapidly deepen westward.

12. As will be noted there is a distinct relation between the underground and the surface folding. In many cases surface exposures check closely, but in some cases no exposures are found and the structure depends solely upon the well log records.

In conclusion, it is important to reiterate that accurate findings depend upon accurate drill logs; and that such records are essential to intelligent geologic work as well as the economic development of oil properties.

METHOD OF ESTIMATING WELL DEPTHS FROM DRILLING LINES

In many cases it is important to know the approximate depth of a well. Where the drillers and operators refuse to give out information, the following method may be employed:

The drilling line is wound on the bull-wheel shaft in successive layers or coils, each consisting of several turns or wraps around the shaft.

The tables give directly the length of line in each coil.

USE OF TABLES

Example.—The length of 2¼-in. Manilla rope on a bull-wheel shaft having 1 coil of 8 wraps is 35.04 feet.

The total length of line on a bull wheel shaft is the sum of the lengths of line in each of the several coils.

Example.—The length of ¾-in. wire line on a bull-wheel shaft having 3 coils of 9 wraps each, and a fourth coil of 5 wraps is the sum of

The length of line in the 1st coil of 9 wraps, or	35.91 ft.
The length of line in the 2nd coil of 9 wraps, or	39.42 ft.
The length of line in the 3rd coil of 9 wraps, or	42.93 ft.
The length of line in the 4th coil of 5 wraps, or	25.80 ft.
Which is a total length of	144.06 ft.

If the length of line in a coil of more than 10 wraps is required it may be computed by multiplying the length of one wrap, as given in the first line of each table, by the number of wraps.

Example.—The length of ⅞-inch wire line on a bull shaft having 2 coils of 20 wraps each is the sum of

The length of line in the 1st coil of 20 wraps, or 4.02 × 20 or	80.40 ft.
The length of line in the 2nd coil of 20 wraps, or 4.48 × 20 or	89.60 ft.
Which is a total length of	170.00 ft.

Table XIII

Tables for Approximate Well Depths

Computed for Bull Wheel Shafts 14½" Dia.—Approx. 3'-9" Circum.

2¼-inch Manilla Rope

Wraps	Coils 1	2	3	4	5	6	7	8	9	10	Wraps
1	4.38	5.56	6.74	7.92	9.10	10.28	11.46	12.64	13.82	15.00	1
2	8.76	11.12	13.48	15.84	18.20	20.56	22.92	25.28	27.64	30.00	2
3	13.14	16.68	20.22	23.76	27.30	30.84	34.38	37.92	41.46	45.00	3
4	17.52	22.24	26.96	31.68	36.40	41.12	45.84	50.56	55.28	60.00	4
5	21.90	27.80	33.70	39.60	45.50	51.40	57.30	63.20	69.10	75.00	5
6	26.28	33.36	40.44	47.52	54.60	61.68	68.76	75.84	82.92	90.00	6
7	30.66	38.92	47.18	55.44	63.70	71.96	80.22	88.48	96.74	105.00	7
8	35.04	44.48	53.92	63.36	72.80	82.24	91.68	101.12	110.56	120.00	8
9	39.42	50.04	60.66	71.28	81.90	92.52	103.14	113.76	124.38	135.00	9
10	43.80	55.60	67.40	79.20	91.00	102.80	114.60	126.40	138.20	150.00	10

¾-inch Wire Line

Wraps	Coils 1	2	3	4	5	6	7	8	9	10	Wraps
1	3.99	4.38	4.77	5.16	5.55	5.94	6.33	6.72	7.11	7.50	1
2	7.98	8.76	9.54	10.32	11.10	11.88	12.66	13.44	14.22	15.00	2
3	11.97	13.14	14.31	15.48	16.65	17.82	18.99	20.16	21.33	22.50	3
4	15.96	17.52	19.08	20.64	22.20	23.76	25.32	26.88	28.44	30.00	4
5	19.95	21.90	23.85	25.80	27.75	29.70	31.65	33.60	35.55	37.50	5
6	23.94	26.28	28.62	30.96	33.30	35.64	37.98	40.32	42.66	45.00	6
7	27.93	30.66	33.39	36.12	38.85	41.58	44.31	47.04	49.77	52.50	7
8	31.92	35.04	38.16	41.28	44.40	47.52	50.64	53.76	56.68	60.00	8
9	35.91	39.42	42.93	46 44	49.95	53.46	56.97	60.48	63.99	67.50	9
10	39.90	43.80	47.70	51.60	55.50	59.40	63.30	67.20	71.10	75.00	10

⅞-inch Wire Line

Wraps	Coils 1	2	3	4	5	6	7	8	9	10	Wraps
1	4.02	4.48	4.94	5.40	5.86	6.32	6.78	7.24	7.70	8.16	1
2	8.04	8.96	9.88	10.80	11.72	12.64	13.56	14.48	15.40	16.32	2
3	12.06	13.44	14.82	16.20	17.58	18.96	20.34	21.72	23.10	24.48	3
4	16.08	17.92	19.76	21.60	23.44	25.28	27.12	28.96	30.80	32.64	4
5	20.10	22.40	24.70	27.00	29.30	31.60	33.90	36.20	38.50	40.80	5
6	24.12	26.88	29.64	32.40	35.16	37.92	40.68	43.44	46.20	48.96	6
7	28.14	31.36	34.58	37.80	41.02	44.24	47.46	50.68	53.90	57.12	7
8	32.16	35.84	39.52	43.20	46.88	50.56	54.24	57.92	61.60	65.28	8
9	36.18	40.32	44.46	48.60	52.74	56.88	61.02	65.16	69.30	73.44	9
10	40.20	44.80	49.40	54.00	58.60	63.20	67.80	72.40	77.00	81.60	10

CHAPTER VIII

FACTORS IN OIL PRODUCTION

The aim of every operator is to extract the maximum of oil in the minimum of time and at a minimum cost. To accomplish this he must map out a definite production campaign. Successful operating depends upon the ability to clearly analyze and comprehend troubles 2000 ft. or more underground. Such ability often saves many thousands of dollars that would otherwise be expended in futile endeavors to remedy some of the troubles that do not exist. Geological conditions 2000 ft. underground may seem largely a subject of conjecture. However, an excellent idea of such conditions can be obtained by a careful study of:

1. Any outcrops of the oil strata and the beds underlying and overlying them.
2. The drill-logs and borings from individual wells, and
3. The cross-sections and the areal maps made from compilation of a number of drill-logs.

From the first sources of information, some clue to the following may be obtained:

(*a*) The hardness of the formations.
(*b*) The thickness of the formations.
(*c*) The dip and the strike of the oil strata.
(*d*) The size of the sand grain of the oil sands.
(*e*) Probable water sands.
(*f*) Evidences of faulting and minor folds that may affect the oil strata.

From the second sources of information may be gained:

(*a*) Knowledge of the actual depths to the oil strata.
(*b*) The number of oil strata.
(*c*) The true thicknesses of the oil strata.
(*d*) The true thicknesses of the overlying beds.

(*e*) The relative productivity of the oil sands.
(*f*) The character of the beds overlying the oil strata, as regards hardness, and whether they are shales or sandstones or limestones.
(*g*) The relative position and number of water sands.
(*h*) The quality of the water, whether alkaline, saline, or sulphurous.

The third source of information gives:

(*a*) The areal limits of the several oil sands.
(*b*) The areal limits of water sands.
(*c*) The changes of oil sands to water sands.
(*d*) The changes of coarse sands to shales.
(*e*) The true dips of the oil sands.
(*f*) The thickening and thinning of the oil strata in accordance with overlap, or of unconformity.

All of the information outlined above is of great value to the oil man who is planning a production campaign. Indeed, the time will come when no operator will begin work on a large scale without taking these factors into consideration.

Problems of the Producer.—Three important problems confront the producer:

1. How best to obtain the largest quantity of petroleum from his own property.
2. How best to defend his property from drainage by neighboring properties.
3. How best to drain the neighboring properties.

At first glance problem 3 may seem to call for illegal actions. Petroleum mining, however, differs from other mining in that there is no legal liability for the operator who depletes a neighboring property, while in mineral mining no operator can obtain ore from neighboring property without being responsible for the mineral so taken. The reason for this difference lies, of course, in the nature of the substance mined.

Petroleum is a fluid, while the minerals are solids. Petroleum, like water, seeks its level and also tends to flow through any outlet that offers easy passage. Such being the case, it is by

no means a simple matter to determine the quantity of fluid that one property may drain from specified neighboring properties. While it is possible to tell approximately how much oil has been obtained from other properties, it is not possible to tell how much oil has been drained from a certain acreage, specifying the amounts taken from each neighboring property. Because of this uncertainty no legal action can be taken against an operator, even though his oil wells may have completely exhausted neighboring territory.

Amount of Oil.—Every operator desires some idea of the amount of oil he may reasonably expect from a property. Estimates of this kind are only approximate, but are useful guides to conservative men. The following factors are necessary in computing the quantity of oil that a property may reasonably produce:

1. The number of oil strata.
2. The thickness of the various strata.
3. The porosity of the oil-bearing formation.
4. The areas covered by each stratum.

The first two factors may readily be secured from the drill-logs. The third factor can only be secured roughly by a study of the drill cuttings and the outcrops of the oil sands. The fourth factor requires careful study of cross-sections and contour maps made from a compilation of many drill-logs.

Assume a property (*Y*) covering a section of land—640 acres in proven territory. (See Fig. 82*a*.) Three productive sands are known. Drill holes Nos. 1 and 5 show three distinct oil sands, *A*, *B*, and *C*, with thicknesses averaging, respectively, 30, 25, and 50 ft., but with a gradual thinning eastward. Drill-holes Nos. 6, 7, and 8 show two sands, *B* and *C*, having an average thickness of 25 and 40 ft., respectively. Drill holes Nos. 9, 10, and 11 show but one oil sand, 30 ft. thick. It is clear that the three strata, *A*, *B*, and *C*, do not all underlie the entire 640 acres under consideration.

The average of each sand that underlies the property is a matter of approximation. Drill holes Nos. 1 and 5 show the

three sands (see Fig. 82*b*) *A*, *B*, and *C*, while Nos. 6, 7, and 8 show *B* and *C*. Evidently the top sand *A* has given out somewhere between Nos. 1 and 6 and Nos. 5 and 8. This being the case, it is safe to assume the limits of the *A* sand at Nos. 1 and 5. This gives 200 acres covered by *A*, and possessing an average thickness of 30 ft. Sand *B*, as shown by the drill records, extends to Nos. 6, 7, and 8, which are taken as its limits. The area covered by *B* is 400 acres, with an average thickness of 25 ft. *C* covers the entire 640 acres, with an average of 40 ft. All

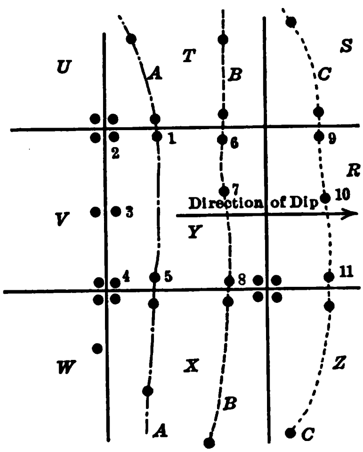


FIG. 82*a*.—Shows plan of wells and limits of sands, *A*, *B*, and *C*.

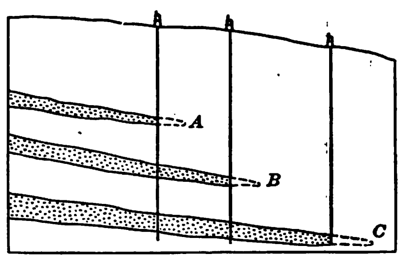


FIG. 82*b*.—Shows cross-section in direction of dip.

told, there are 200 acres 30 ft. thick, 400 acres 25 ft. thick, and 640 acres 40 ft. thick; or 200 × 30 = 6000 acre-ft., + 400 × 25 = 10,000 acre-ft., + 640 × 40 = 25,600 acre-ft.; a total of 41,600 acre-ft.

This total is a fair estimate of the aggregate amount of oil sand underlying the section. The porosity of oil formations differs so materially that no constant should be assumed except as an approximation. Sands show from 5 to 20 per cent. porosity, and some dolomitic limestones as high as 35 per cent. Gen-

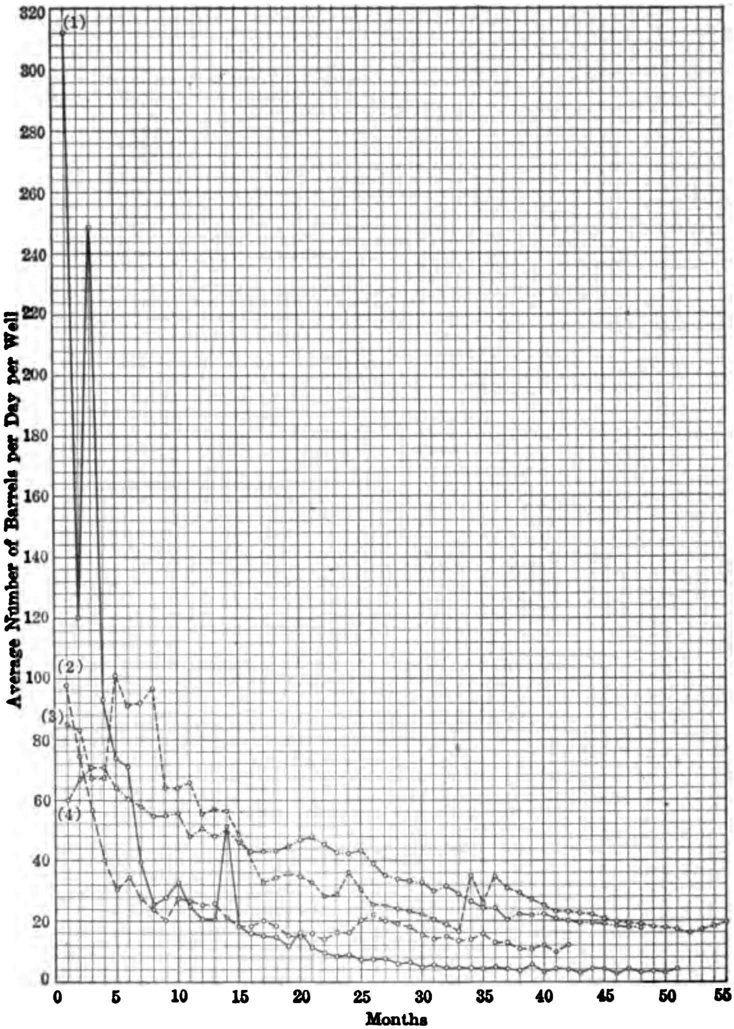


FIG. 83c.—Typical production curves of wells in the Mid-continent oil field. Curves represent production under leases as follows: 1, Muskogee district, Oklahoma; 2, Bartlesville district, Oklahoma; 3 and 4, Glenn pool, Oklahoma. (After U. S. Bureau of Mines.)

erally, however, 10 per cent. is accepted as the basis for estimates. The U. S. Geological Survey accepts 10 per cent. in most of its computations. One gallon per cu. ft. is often taken, or nearly 1000 barrels per acre-ft.

For the purpose of illustration, the latter estimate will be assumed. Thus, 41,600 × 1000 = 41,600,000 bbl. of oil underlying the property. It is safe to assume that only 50 per cent. of this oil is recoverable.

Production Curves.—Another method based upon the history of adjoining leases gives an excellent means of arriving at estimates of what wells under similar conditions should do.

The numbers at the left of Fig. 83*c*, page 110, show the number of barrels of oil the wells produced.

The figures at the bottom give the number of months the wells have produced.

The jagged lines show the production from month to month. As one can see, the production drops steadily the longer the wells are operated.

Daily decline lines or curves may be computed in the same way.

As the lines show, the initial or flush productions are large but rapidly decrease with age. No. 1 shows a high production of 312 bbls. at the end of first month; 120 bbls. at the end of the second month; 248 bbls. the end of the third month; 92 bbls. the end of the fourth month; 75 at the end of the fifth month, etc. At the end of the first year the production was 20 bbls; the end of the second year was 8 bbls.; and at the end of the fourth year less than 4 bbls.

Such a method gives an excellent working basis for computing expected performance of nearby properties.

Losses.—Experiments made by the U. S. Geological Survey (see Bull. 475, pp. 2 to 16) show that with Pennsylvania and Illinois petroleum of 0.810 (43° B.) and 0.8375 (37° B.) specific gravity, respectively, fuller's earth will absorb, on an average, 40 per cent. of oil that cannot be recovered. Experiments have not yet been made to ascertain the percentage of oil retained by

the coarser-grained oil sands. With heavier oil of increased viscosity it is safe to assume fully as large a loss as that given with fuller's earth.

Added to this loss, by retention due to adhesion and friction, is the incomplete drainage of the oil sands by drilled wells. This last factor is most important. There comes a time when the oil accumulates in the well so slowly that there is little economy in pumping it. When this point is reached, the oil property is abandoned as of too little value to pay for operating. It is economically exhausted, though not actually so. The above losses do not take into account possible flooding, cave-ins, or drainage by neighboring properties. When all these factors are considered, 50 per cent. seems too high an estimate. However, for general purposes this figure is acceptable. There are, then, 20,800,000 bbls. of oil that may be extracted from the property under consideration. Call this figure 20,000,000 bbls. for safety.

Acreage per Well.—The next step is to find the number of wells that will be needed to obtain this oil. Here again assumptions are necessary. The area drained by one well is variously estimated at from 1 to 10 acres. Little definite information is available as to the acreage per well that gives the best results. Four to five acres is accepted as good practice, but whether or not this is the best figure, cannot be said at present. Some operators space their wells 100 to 800 ft. apart, varying the distance inversely with the richness of the "sands." Taking 5 acres as a basis, 128 wells per section (640 acres) would be required.

In some estimates, 1 well to 8 acres is considered ample, or 80 wells per section. No rule can, however, be set, as the porosity of the sand, the gas pressure, and the dips vary greatly in different fields.

The more porous the sand, the stronger the gas pressure and the greater the dip, the less number of wells required to drain a property. With compact sandstones, low dips, and weak gas pressures, more wells will be required. The writer has personally

known wells 500 ft. and 600 ft. apart to draw oil, one from the other, but the sands were porous, the dip 18 ft. to the 100 ft., and the gas pressure large. On a structure with steep dips it is better to locate wells closer together across the dip than down the dip.

Dry Spots.—In some producing areas, it is not uncommon to find non-productive spots in the midst of producing properties. Such spots may be due

1. To local hardening, or cementation of the sand grains.
2. To island conditions, left as a result of unconformities.
3. To lensing of the oil sands.
4. To deep seated faulting.

None of these conditions can be foreseen, unless there are a number of drill logs available, or the history of a field points to such conditions.

Operating Problems.—The problem of securing the greatest quantity of petroleum from a property is intimately associated with the problems of securing:

1. The greatest quantities of petroleum from the neighboring properties, and
2. Protecting property from drainage by others.

Many other minor problems, such as water troubles (sometimes a serious menace to a whole oil field), cave-ins, collapsed casing, leaks due to filling of dry sands, and others, will be treated after considering the main problems of well-location. Consider the problems involved in securing oil from neighboring properties. Fig. 82*a* shows a number of properties surrounding *Y*; there are *U*, *V*, and *W* above *Y* on the dip; there are *T* and *X* on the sides of *Y*; and there are *S*, *R* and *Z* below *Y* on the dip. The three sets of properties require different treatment for offense and defense. In a new field where the gas pressure is strong, the oil generally tends to migrate upward from points on the lower dip. However, in olders fields, the tendency of the oil is to move downward under the effect of gravity. Friction, in some cases, especially where the dip is slight, will keep oil from traveling downward.

Offensive Tactics.—The usual practice of offense consists of the following elements.

1. To sink wells before neighboring companies drill.
2. To drill holes of larger diameter than those of the neighboring companies.
3. To drain sands unknown to the neighbors.
4. To place the wells so as to be sure of draining as much territory as possible.
5. To speed the wells as fast as possible.

It is almost a self-evident fact that the first well in a field has an advantage over all other wells, other things being equal. If one company completes a well a month ahead of another, it is but natural that the first well will take the cream of the production. But more than this is likely to happen. The first well may form channels which will effectually drain a territory, and a neighboring well or wells will suffer in consequence. (See Fig. 84.) This was supposedly the reason for the barrenness of the wells contiguous to the Lake View gusher. In this case the theory seems correct, as recent reports indicate that wells nearby have greatly increased in production since the great gusher ceased flowing.

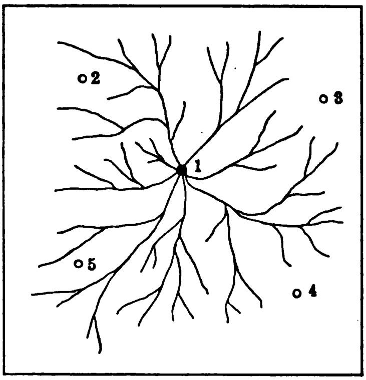


FIG. 84.—Illustrates how well No. 1 drains oil from Nos. 2, 3, 4, and 5.

Casing Sizes in Wells.—Wells that have 8-in. casing certainly have an advantage over wells that have diameters of 4 and 6 in. The larger casing will stand more rows of perforations, which means a greater surface exposed to the oil. Also, the interior of the casing will give a larger collecting basin for the oil. In this latter case the ratios of the larger casing to the small will be 8^2; 6^2; 4^2 or 64 : 36 : 16. Thus the 8-in. hole will give four times the collecting basin of the 4-in. hole and nearly twice the basin of the

6-in. hole. However, the relative exterior surface exposed to the oil sands will not bear the same ratio. Perforations vary greatly in size, from 3/8 by 3/4 in., 3/8 by 2 in., 1/2 by 1 in., to 1/2 by 3 in. and larger, depending upon the different companies. Generally these perforations are in longitudinal rows and evenly spaced, one every foot or 6 in. A 4-in. casing is given three rows of perforations, a 6-in. casing four rows, while an 8-in. casing carries five to six rows of machine-made slots. Where a rolling knife or casing "splitter" is used, there is little regularity of rows. If the size of the perforations is the same and the spacing equal, the ratios are 6 to 4 to 3. The 8-in. casing exposes twice the surface of the 4-in. and one and one-half times the surface of the 6-in. The advantage then is certainly with the larger casing.

It must not be supposed that the increase in the amount of oil obtained is in proportion to the ratio of collecting area, or of perforated area. However, where the sands are fully saturated, the advantage is with the larger casing.

The sizes of holes given above apply more particularly to pumping wells. Where flowing wells occur, smaller holes, such as 3-in., have of necessity been used, in deep territory, 3000 ft. and over. The gas pressures in flowing wells are large and when confined to small casings have greater pressures than in larger holes. In small holes one can obtain large productions, 3000 to 8000 bbl. with less danger of injuring the wells than by letting them flow freely through larger casings.

Oil Well Screens.—Oil well "screens" or strainers are often used instead of ordinary perforated casing. Screens or strainers are especially adaptable to soft, running sands. There are a number of types of screens or strainers upon the market:

(1) The plain perforated screen; (2) the button type; and (3) the wire wrapped type.

All three types of screen have been used but the most successful and popular strainer is the wire wrapped type.

The perforated screen consists of casing with horizontal or vertical slits cut into the pipe.

The button type is made by drilling circular holes in the casing

and then placing copper buttons, with varying sizes of slits in them, into these holes.

The wire wrapped screen is made by perforating casing as in the button type and then wrapping the casing spirally with wire. The wires are so spaced that spaces from 0.004 in. to 1/8 in. can be used. The wire is on a bevel on the inside. This feature of the V-shaped wire is to prevent any particles of sand that work through the outer face of the screen from wedging tight around the perforations. (See Fig. 85.) The per cent. of the open space exposed to the oil sand is from 2 to 3 times that of the ordinary, perforated casing.

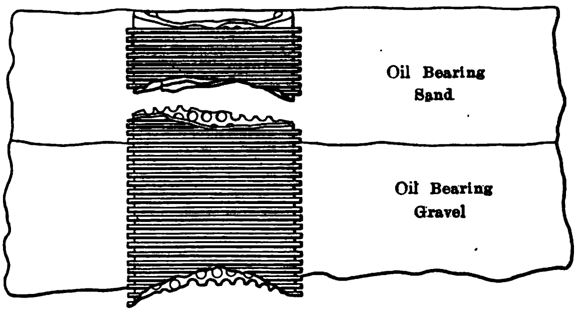


FIG. 85.—Oil well screen.

Unknown Oil Sands.—It may seem a rare occurrence for a company to tap oil sands unknown to its neighbors. This, however, is not unusual, especially where companies have failed to prospect for deeper sands. It is then discovered too late that more venturesome neighbors have tapped the deeper sands and gained a good production at the first concern's expense, having drained much of the property of the careless operator.

Competitive Adjacent Properties.—Again, companies often wilfully hold back information regarding their prospect holes, and give misleading information as to lower sands. However, no company is under moral obligation to give information to competitors, unless prospect holes show water sands that may

endanger the neighboring properties as well as their own. There are, however, cases that have been reported where concerns have deliberately flooded a field, or portions of it, to drive the oil from neighboring properties to their own, or where by destroying neighboring lands these companies have benefited by a loss of competition.

The question of placing wells so as to drain the largest possible territory involves some interesting problems. One case in particular seems worthy of study. In one of the Oklahoma fields, an independent operator held a very good oil property which he desired to develop. Upon investigation it was found that the only

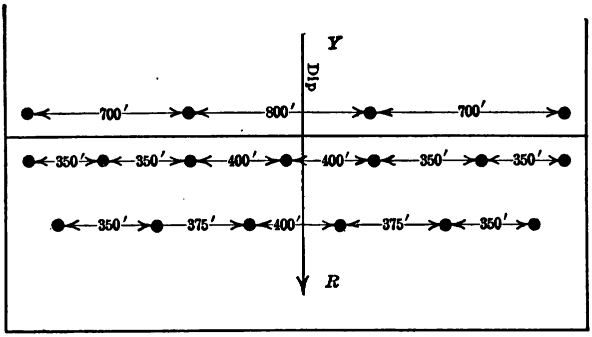


FIG. 86.—Offensive system for property *R*.

pipe line in this field was owned by a company which owned held leases on all the neighboring land. The independent operator could not afford to build a pipe line of his own, and the corporation held him up for transportation. Obviously, the only thing he could do was to keep his land. Unfortunately for him, the opposing leases were lower on the dip, and as the opponent was developing its properties, the independent man was forced to give up hope of getting any oil from his property. The stronger concern would not buy his land, so that in time the property was exhausted without the independent obtaining anything for his share. While this is an extreme case of drainage, the same principle applies to nearly all oil fields where one company is favorably situated to drain oil from others.

The principal elements considered in placing a well to best drain a neighboring property are: (*a*) The spacing of wells, and (*b*) the degree of dip of the oil sand.

Where an opposing company has already sunk its wells, there are certain lines of procedure that may be successful. If its wells are far apart it will be of advantage to place wells at intermediate points as well as opposite the other wells. (See Fig. 86.) The wells on *Y* are spaced 700 and 800 ft. apart. Wells on *R* may then be spaced 350 and 400 ft. apart. This will force the *Y* operators to drill wells between the others. This being the case, the *R* operators have the advantage of being down the dip, and by placing back wells at points intermediate between the first row of wells (see Fig. 86), effectually cover all the line presented by *Y*, and having more wells, should draw the oil more rapidly than the single line of wells. This condition is by no means a theoretical one, but exists in a number of places, though often quite unnoticed.

Speeding Wells.—Speeding the wells as fast as possible is one of the means of obtaining more oil than neighboring companies. But there is a decided limit to such speeding. There must first be oil enough to pay for pumping wells rapidly. In some places the oil seeps into the well basin slowly and is pumped off in a few hours. Rapid pumping is here needless and expensive. In other places there is plenty of oil, but rapid pumping produces unfavorable conditions, such as drawing large quantities of sand into the well, and consequent trouble with the well.

Then, too, there is a limit to the speed that the pump rods (sucker rods) will stand without breaking, and to the effect of the speed upon the pumping jack or upon the derrick and the machinery.

In some cases where the yield of the wells could be increased, the effect upon the machinery might result in serious breakdowns and accidents. A rational method of offense would combine all the elements outlined above.

DEFENSIVE TACTICS.—The problem of defense is next in order. The elements to be considered are much the same as those of

offense. If a neighboring property is being drilled, wells must be drilled to offset the neighboring wells. If a neighbor finishes his wells with casing of large diameter he must be met with the same size or larger. If the neighbor penetrates sands not before known to exist, then the wells must be deepened to offset the wells of the neighbor.

If there are two properties, *W* and *X* (see Fig. 87), with an anticline running through them, and plunging southwest as shown by the arrow and the underground contour lines, locating is by no means as simple as most operators would think. If a well on *W* is placed on the axis of the anticline, the *X* operators without studying the geological side of the question would ordi-

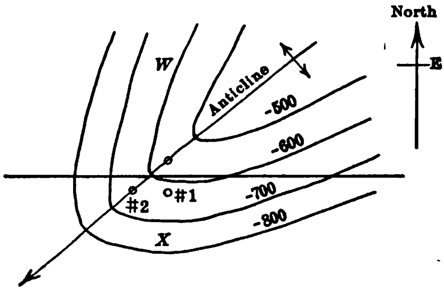


FIG. 87.—Offensive method employed by *X* to drain *W*.

narily place an offsetting well at location No. 1. The location at No. 1 does not, however, properly offset the *W* well which is drawing oil from both flanks of the anticline and along the axis. To offset the *W* well place a well on *X* at No. 2. By placing a well in this way No. 2 pulls oil from both sides of the anticline and being lower on the plunge of the anticline will draw oil from the *W* well, thus effectively protecting the *X* property.

Even if the *W* well has not been drilled it is best to locate a well on *X* at No. 2, as a well at that location draws from both sides of the anticline and from below. To offset the *X* well the best possible location on *W* would be on the axis of the anticline. Even then the *W* well is at a disadvantage as it is up the plunge from No. 2 and the oil will naturally gravitate to No. 2.

Often (indeed, in most cases) a property may embody the principles of offense against properties higher on the dip and defense against properties lower on the dip. Thus, in Fig. 82*a*, the properties *U*, *V*, *W*, *T*, and *X* are on the defensive against *Y*; and *Y* is on the defensive against properties *S*, *R*, and *Z*; also, in Fig. 86, *Y* is on the defensive against *R*. In this latter case, when wells are drilled on *R* intermediate between those on *Y*, the operators on *Y* should have met this attack by drilling wells to offset those on *R*. When the *R* wells are pumped rapidly the *Y* wells must be speeded to meet the increased drain. Indeed, the *Y* property is at a decided disadvantage as regards attacking *R*. Such being the case, all that can be done is to keep up as vigorous a defense as is possible under the conditions. Different systems of offense and defense have been worked out by many companies. However, the problems presented here embody the essential features of such systems.

Key Wells.—An interesting application of geology occurs especially in the Kern River field of California, where water

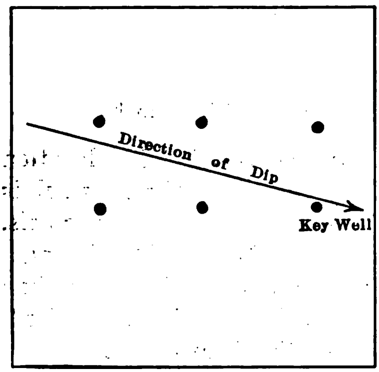


Fig. 88*a*.—Relation of key well to other wells.

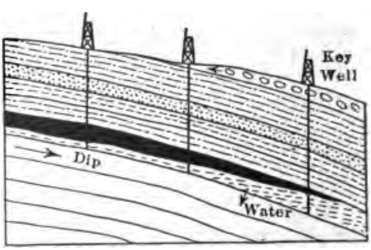


Fig. 88*b*.—Cross-section showing drainage by key well.

troubles are greatly lessened by what is called the "key-well" system. Fig. 88*a* shows six wells located on a monocline. The direction of dip is shown by the arrow. The cross-section (Fig. 88*b*) shows the underground structure.

Water naturally gravitates toward the lower well. By using an air-compressor, water may be pumped from the formation very rapidly. By this method of pumping, one well can withdraw most of the water from the oil sand and lower the percentage of water in the petroleum that comes from the other wells. In some cases, production has been increased from 100 to 500 per cent. besides lowering the water content. The explanation of

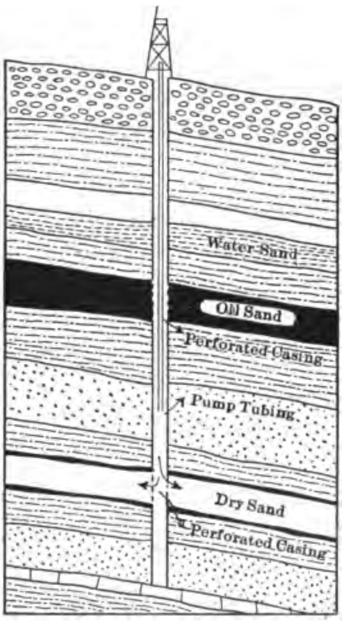


FIG. 89.—Shows oil entering dry sand below.

this increase in production seems to be in the fact that water and oil form a heavy emulsion that does not pump readily and also seems to clog the water sands. The decrease in water pressure also keeps the water from driving back the oil.

The method shown above may be reversed. In Pennsylvania and West Virginia water is introduced into the lower well under great pressure. The water forces the oil up the dip to the oil

wells. Wells that produce from ¼ to 1 bbl. have gained to 3 and 4 bbls. per day. Of course, such a procedure is not sanctioned by law, but it has been employed, nevertheless.

Compressed air has been employed to recover oil. The air is forced into the oil zone through a well, or wells, and the oil is forced to migrate from the neighborhood of the key well or wells to wells that are pumping oil. Compressed air, used in such a way is expensive, but favorable results have been achieved.

Vacuum pumps are used in many places to secure casing head gas, and also to increase oil production. The suction induced by a vacuum is sufficient to cause a flow of oil to the wells on which the vacuum pumps are used, and to completely rob other neighboring wells not employing a vacuum.

Dry Oil Sands (See Fig. 89).—Dry oil sands may cause a loss of production little suspected by many operators. Where wells are drilled deeper than the productive strata, and are left open or free of casing below the oil sands, petroleum will fill the lower dry sands and escape. This condition occurs in some wells that have been drilled carelessly. Wells are sometimes pumped far below the productive strata. Such cases are due to a carelessness, but they exist. Where there are holes in the casing similar leakage may result. The remedy, of course, in the latter case is to replace the casing; in the former, to plug the hole just below the oil sand.

Gas will escape in a similar manner. Indeed as gas can travel where oil cannot, gas is even more likely to escape than oil.

Underground Mapping.—In many fields, after careful cross-sectioning and contouring, it has been shown that in places productive sands have been passed through without being known. Later, by perforating the casing in the old wells or by drilling new ones, production has been obtained from the neglected sands.

Practical Application of Structure Contour Maps.—A properly made structure contour map will bring out points that may save many thousands of dollars in later oil fields development. Two illustrations of such usage are enough to show some of their advantages to the oil man.

Case I.—Fig. 90 shows a gas well at No. 1, an oil well at No. 2 and a dry hole at No. 3. The question now is where should the owner of "*X*" locate next to secure a well. The producing well at No. 2 is practically on the 980 level; No. 3 is just below the 980 contour. By following it around it is seen that the edge of that level is near the edge of "*X*." Therefore there is little

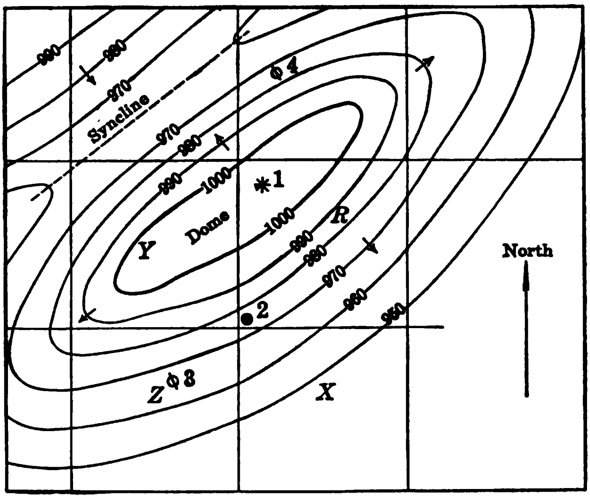


FIG. 90.

chance for property "*X*" to obtain wells below the 980 line, and the property should be abandoned. Likewise No. 2 sets the limit of drilling on the "*R*" property. However, a dry hole at No. 4 on the West is shown above the contour line of 970, but production is not limited there. This is notably the case where the normal dip is broken by a short reversed dip.

Case II.—A property is for sale. What will be the possibilities for oil on that property? From the map it is plain that there is a chance to obtain as good producing wells on "*Y*" as on "*R*," as

the 980 contour line includes all but a small portion of "*Y*" within its limits.

Property "*Z*" will be of little value though there is a possibility of a line of wells along the north boundary on the same level as well No. 2.

CHAPTER IX

WATER, THE ENEMY OF THE PETROLEUM INDUSTRY

There are two main sources of water in all oil fields: water confined in the oil-bearing strata, and water occurring separate from the oil zones. In the first case water is sealed in the oil sand and normally underlies the oil and gas. It may be sulphur or salt water, or, in fact, may contain many minerals. Originally it was meteoric or rain water that percolated through the earth until it reached the oil strata, where it was sealed or held in by the shaly or clayey beds that generally are found above and below the oil sands. In some cases, however, this water is the sea water penetrating the shales and sands before folding occurred. This water is generally under rock or gas pressure and as it is already in the oil zone, there is no way of eliminating it as a source of trouble. However, where there are two or more oil zones and but one is troubled with water, there may be great economy in shutting off one of the troublesome zones. On the whole, water confined to the oil zone is less dangerous to the industry than water occurring in other than the oil zone. It may occur above, below, or between the oil strata. (See Fig. 94.) Generally under head and occurring in large quantity, it becomes a source of great danger to an oil field when it enters the oil zones; indeed, it is the water most to be feared and to be guarded against. Obviously, such water enters the oil zones only as the result of artificial or man-made causes, as the oil zones and water-bearing strata are separate and distinct. Earthquakes or volcanic upheavals may cause faulting and shattering of the formations to such an extent that water enters the oil zones from the separate water sands, but for all practical purposes the latter causes will not be considered.

Two sources of water have been discussed. For the sake of

clearness all those waters originally confined in the oil zone will be called *primary* waters, and all waters occurring in strata separately from the oil zones and entering the oil zones from artificial causes will be called *secondary* waters. These definitions refer to the original sources of the water. The terms "bottom water," "surface water" and "edge water" are in constant use by oil men to express the occurrence of water in oil zones, especially in newly drilled wells. As these terms do not take into account the source of the water, whether or not it was originally confined in the oil zone by natural processes or whether or not it was introduced by artificial means, the more exact classification as given above will be used.

Primary-water Troubles.—*Primary water*, as before mentioned, lies at the bottom of the oil sand under pressure. As the gas and

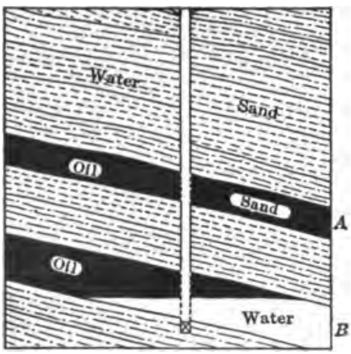


FIG. 91.—Water in partial control of zone *B*.

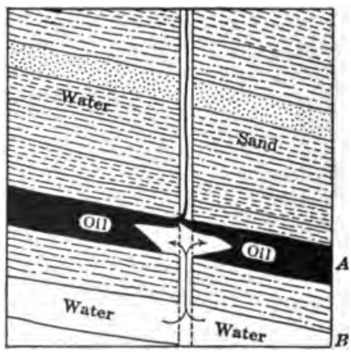


FIG. 92.—Water in full control of *B* and entering *A*.

oil are withdrawn from the sand the water rises to replace them. In time, nearly all the oil is drawn from the sand and only the water is left. The field must then be abandoned. This is the result of natural exhaustion and is expected in every field. Where there is but one oil zone, little avoidable danger or trouble occurs. Assuming, however, two strata (Fig. 91), as commonly is the case, water will rise from the lower stratum *B* into the

upper stratum *A*, unless proper precautions are taken to avoid this condition. Where the gas pressure is strong the water in *B* will be driven into *A*. Especially is this true when zone *B* becomes all or nearly all water. (See Fig. 92.) By properly confining the water to the bottom zone, water troubles would be averted for a time. Again, there is an extreme condition, as shown in Fig. 70, in which the water takes possession of *A* and then enters *B*. This condition requires that the water in *A* be kept from *B* by methods differing from those used in the two previous cases. These methods will be discussed later.

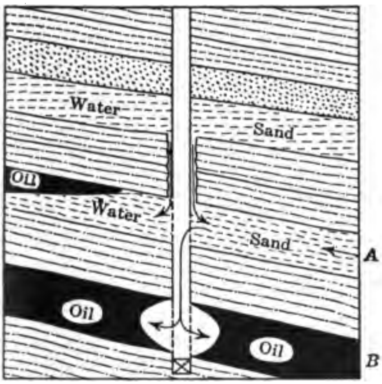


FIG. 93.—Water in partial control of *A* and beginning to flood *B*.

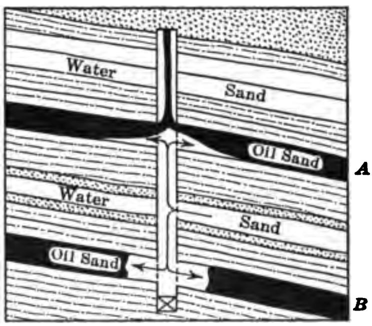


FIG. 94.—Water between *A* and *B* entering both sands. Water above *A*.

Figs. 92 and 93 illustrate the extremes of water flooding. These conditions are theoretical, but are closely approximated under actual conditions. Generally all the oil is not driven from the well, but some remains as an emulsion of finely particled oil and water which is very difficult to treat. However, the two cases given set the limits within which all primary-water troubles of the flooding type may be placed.

Secondary-water Troubles.—Secondary water enters the oil zones due to four causes, namely: (1) Accidents to the casing, used in shutting off the water sand; (2) faulty cementing of the

water sand; (3) cave-ins due to the withdrawal of a large quantity of sand from the oil stratum, thus allowing water to enter the oil zone from above; and (4) where no effort has been made to shut off the water formation, especially in prospect holes.

Accidents to the casing that shuts off the water may result from the dropping of sharp-pointed tools, bailers or sand pumps into the hole, or from falling tubing. The casing may be corroded by the action of the minerals in the water, and later collapse. The eroding action of sand in a flowing well is often sufficient to cut the casing. Sometimes the casing is defective or is not put together properly. Again, the sudden shifting of the sands in the oil zone may cause the casing to pull apart or break at the water string.

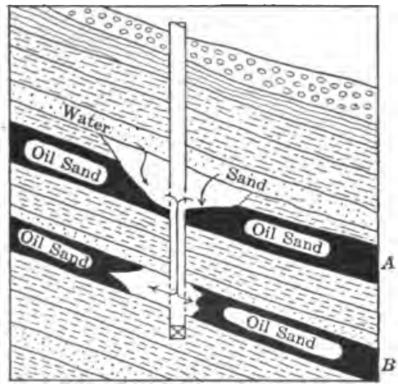


Fig. 95.—Water from top stratum entering zones *A* and *B* due to caving of shale above *A* resulting from withdrawal of sand.

Accidents to the cement may result from the same causes as enumerated above, without, however, affecting the casing to any marked degree. Again, the cement may be improperly mixed; the action of the water upon it may destroy its efficiency; or it may be so porous that it will not withstand the water which seeps through it, and in time wears large channels. Where the water pressure is great, the cement may be ineffective.

Cave-ins around the casing (Fig. 95) are of common occurrence in the California fields.

Where large quantities of sand, often 50,000 to 100,000 cu. ft., are taken from the oil zones, there must of necessity be left some form of cavity underground. This cavity leaves the roof above it unsupported. Where this roof consists of soft shale or

clay cave-ins are inevitable. If the distance between the oil zone and the water stratum is slight, such a cave-in would assuredly admit water to the oil sand. As this question is one of great importance a fuller discussion will be given farther on.

In cases where no effort is made to shut off water the consequences are often very dangerous to the life of the field. Then the water has free scope and soon floods the near-by portion of the field and later may spread over a large extent of good territory. "Wildcat" drillers are especially prone to neglect the proper precautions to shut off water. When the speculator strikes oil, he sells his property and leaves the purchaser to shoulder the burden of responsibility. Sometimes these properties stand idle a long time and in consequence become worthless.

Determination of the Source of Water.—It is no easy matter to determine the source of the water or the cause of its appearance in a well. To effectually remedy water evils, such information is essential.

There are four sources of evidence from which one may draw the needed information, as follows: (1) Evidence derived from the chemical and physical properties of the water itself; (2) from the neighboring wells as shown by their structural relation to the well in question; (3) from the drill logs, and (4) from mechanical tests made on the wells by using drilling tools, plugs, bailers, pumps, testers, etc.

1. CHEMICAL AND MECHANICAL TESTS OF WATER.—The evidence derived from the study of the chemical and physical properties of the water is unreliable except in a few special cases. Both the primary and secondary waters may have the same composition due to their similar origin. This, however, is not always the case. Sometimes the primary water may be saline and the secondary sulphurous.

In this case, or in similar cases, no difficulty would appear. There are, however, oil fields in which the secondary water is saline and sulphurous in different parts of the field, but in the same geological horizon. Obviously, the occurrence of salt or

sulphur water in the oil zone would mean nothing definite in such a case.

Where careful tests have been made of all the waters in a field, the presence of a new or unusual water in the oil zone would point to a primary water. It is, however, almost impossible to obtain careful analyses of all the waters in a large oil field and to properly correlate them. Waters in the same horizon and but a quarter of a mile apart often differ greatly in their percentage composition of salts. Again, the waters in the oil zone may show marked differences. Such being true, it is obvious that little reliance can be placed in chemical and physical tests unless exhaustively made to completely cover an entire field. Taken in conjunction with other evidence, however, the chemical and physical differences of waters may be of marked value in assisting one to determine the source of the water.

2. EVIDENCE OF NEIGHBORING WELLS.—The second source of evidence gives some valuable aids. If the water is confined to but one well while the wells on all sides show no water, then the water must be local and secondary. In such a case look for defective casing, defective cement, or for a cave-in.

If the neighboring wells higher on the dip of the anticline, monocline, terrace or other structural feature show water, while the wells below do not, then the water is secondary and one must look for causes in keeping with such a source.

If the wells below show water, while the wells above do not, then the evidence points to primary water. This, however, is not conclusive unless it is known that the lower wells have no casing troubles or give no evidence of cave-ins.

If the wells both above and below show water, then the evidence points to either primary or secondary water, unless the percentage of water in the wells increases lower down the dip. In such a case the evidence points to primary water. This is not conclusive by any means, since the closer one approaches to a leaky well the greater is the percentage of water in the oil. This evidence, however, gives one a clue that may prove of great value in solving water problems.

INDICATORS.—Indicators have been successfully used in many cases to trace the source of certain waters, to determine the rate of travel of underground waters and like data. As applied to oil, their use is quite limited. Such tests have in some cases proved successful. These cases were where the wells were close together. Where two or more wells are within 300 to 500 ft. of one another, indicators can be used successfully, but it is by no means easy to test wells several hundred yards apart by this means. The rate of travel of the indicators is so slow, the area over which the indicator will spread so large, and the final quantity of indicator received so small, that it is out of the question to use indicators successfully unless a well-defined channel exists between two wells.

3. EVIDENCE OF THE DRILL LOGS.—The third source of evidence, drill logs, is extremely useful. The drill logs show the number of water sands and their relation to the oil sands. From these logs one can also determine the thickness, the hardness, and the quality of the strata lying between the oil zone and the water formation. The character of the oil sand itself is also shown in properly kept logs. These facts are all important in determining the probable conditions in the well.

If the roof or capping overlying the oil sand is several hundred feet thick, the probability of a cave-in is greatly lessened. If the roof consists of a hard sandstone, or of shale interlain with sandstone layers several feet thick, the probability of cave-ins admitting water is almost nil. Where a few feet of shale separate the water formation from the oil zone, cave-ins would undoubtedly admit water to the oil zone.

If the oil formation consists of a coarse gravel, cave-ins would be precluded. The fine sand is drained from the gravel leaving minute interstices between the pebbles but no large cavity, consequently an unsupported roof is not very likely.

Cave-ins result in the presence of a large quantity of shale in the oil, in collapsed casing, and often in a diminished production of oil. Underground cavities play a more important part in the life of an oil well than is generally accredited to them. Especially

is this true in the California and the Russian oil fields, where the oil strata consist generally of unconsolidated sands that are readily pumped from the well. The presence of dangerous cavities would seem to depend in these fields upon the dip of the oil sands. Surface observations show that saturated oil sand has an angle of repose varying between 10° and 15°, or a slope of between 17 and 24 ft. in 100 ft. The greater the degree of saturation the less the angle of repose within the limits imposed. Such being the case, it would follow that where the dip of the oil stratum is equal to or greater than the angle of repose no cavities would exist around the casing. The angle of repose would be modified to some extent by the gas pressure and also by the back pressure exerted by the column of oil that rises in the casing. The underground angle of repose should, however, approximate the angles determined from observations taken as the sand stands in the sump holes. As the likelihood of cavities depends upon the degree of dip of the oil strata it is evident that where the angle of repose is greater than the degree of dip, cavities would occur around the casing.

4. Evidence of Mechanical Tests.—Mechanical tests are any tests made by means of the tools and other implements used in drilling operations. These tools are generally bailers or sand pumps (see Fig. 73), packers and plugs (see Figs. 97 and 98), casing testers, and lifting pumps. Swedges may also be included. By placing a casing tester below the water string it is a simple matter to test for leaks in the casing.

The casing tester is a temporary plug that will not allow water or oil to pass either above or below it, as it fits snugly inside the casing. The oil and water above the tester are bailed or pumped out of the hole and the tester is then left in the well a few hours. Later the hole is bailed or pumped out and the fluid examined for evidence of water. The same method applies to testing the oil zones for water. The casing tester is placed below the top oil zone and this zone is then tested either by bailing or pumping. If it is desirable to test the lower zone a different procedure is necessary. A tubing packer is placed low enough on a string

of tubing to shut off the upper oil zone or zones and the lower zone is then tested by means of a lifting pump or by using a bailer of a smaller diameter than the tubing. If the casing has collapsed and will not admit a tester, a swedge (see Fig. 99)—a spindle-shaped and somewhat bulbous tool—is introduced into the hole and used to clear a passage for the tubing.

By means of mechanical tests the condition of the casing is determined. The particular oil zone or zones that are troubled with water are shown and leaks in the water string are located. Further than this the mechanical tests cannot go. If water is present in the oil zones, it may be primary or secondary. If the latter, it will come from neighboring wells or cave-ins around the casing; if the former, it will show in wells lower on the dip. Such being the case, it is clear that mechanical tests must be used in conjunction with the other sources of evidence to obtain the best results. No single source of information furnishes absolute proof.

Fig. 96.—Dart bottomed bailer.

Fig. 97.—Wall packer.

Fig. 98.—Rubber plug.

Fig. 99.—Swedge.

Treatment of Primary Water Troubles.—Primary water, as already stated, ultimately replaces the oil in every field. This being true, the only course left to the operator is to prolong the life of the well by taking every proper precaution to take the oil from above the water level. If the primary water level is known, it is not a difficult matter to place a wooden plug or bottom packer a few feet above the water level. In this way the oil is taken from the well without taking much if any water. Slow pumping is also required so that the water will not be disturbed and drawn out with the oil as an emulsion of oil and water. As the water rises new plugs must be inserted until the oil is exhausted.

Where there are two or more oil zones, one of which has gone to water, it is best to isolate the faulty zone. This may be done in several ways: where a lower zone causes the trouble a bottom packer placed above the lower zone and below the upper zone or zones effectually keeps the water shut off. A bottom packer consists of a rubber plug with a tapering hole in it. A mandrel is driven into this hole (see Fig. 98) causing the rubber to expand, thus effectually plugging off the lower stratum. Where the troublesome zone is an upper zone, other methods must be used. In this case, the stratum will be treated as a water stratum and shut off by means of wall packers, seed-bags, cementing methods, or by setting the casing in a clayey or shaly bed. These methods require the pulling of the casing and perhaps a redrilling of the well.

Wall packers (see Fig. 97) consist of two metal cylinders between which is placed a rubber cylinder, secured to the metal cylinders by some suitable device. By putting pressure upon the metal cylinders the rubber is caused to expand. This device is placed on the outside of the casing and by means of a spring, or simply by means of the pressure of the casing, the rubber is caused to expand, closing the space between it and the wall of the drill hole. There are several different styles of wall packers, but the principle is the same.

Seed-bags are bags filled with flaxseed, beans, peas or wheat. These bags are placed at the bottom of the hole, preferably in

some clay or shale formation. The bags fit the holes snugly and are rammed down with the drill bit. The casing is then let down upon the seed-bags, forcing part of the seeds between the casing and the wall of the hole. The seeds expand under the action of the water, and act as an effectual barrier. Later, the bag inside the casing is drilled through. In some cases bags are tied around the casing and let down into the hole.

Cementing methods have become very popular for shutting off water. Several different methods are in vogue. One requires that the casing be lowered into a bed of cement which fills the hole to some distance above the water sand. The cement hardens and later the cement inside the casing must be drilled through to reach the oil sand below.

Another method requires that the casing be placed in the hole and raised above the water stratum a short distance. Cement is gradually pumped into the hole under high pressure and the casing then lowered. As the cement hardens it forms an effective barrier to water entering the drill hole and also keeps the water from coming in contact with the casing and corroding the same Cementing material may be pumped into the drill holes or may be dropped in by means of bailers or tin tubes.

One of the most effective and also the simplest methods of shutting off water sands consists first of drilling 10 or 12 ft. into a good clay or soft-shale bottom. The drill hole is then filled with fine mud to the height of 10 or 12 ft. The casing is let down on the bottom of the hole, the fine mud settles around it and when later drilling is continued through the casing, the mud around the casing forms a water-tight joint effectually sealing off the water stratum. Generally, however, the casing is driven 10 or 12 ft. into a shale.

Various other methods of shutting off water are used in different parts of the world, but the several methods described above are the principal ones.

Treatment of Secondary Water Troubles.—Secondary water troubles are treated in a manner similar to primary water troubles. Where the casing is defective it must be withdrawn

from the hole and replaced with new. This requires re-cementing and calls for the methods outlined above. Where the cement in the hole is at fault the casing must also be pulled, and the casing reset and re-cemented.

Where there have been cave-ins no safe method of procedure can be laid down. If a great deal of water enters the wall it may become necessary to abandon it. This is true especially where there is but a single oil sand, but where two or more sands are present, the zone in which the cave-in has occurred may be isolated by one of the several methods used to shut off water sands.

Prospect holes, especially "wildcat" holes, when carelessly finished may threaten the life of an entire field. In some states such holes must be plugged. The law specifies the size of plug and the amount of covering above it. The importance of taking proper care of these holes must not be underestimated. The true remedy for flooding does not by any means lie in the treatment of water after it appears, but in taking every possible precaution to see that the casing and cement are intact when the well is first brought in. Later, accidents may happen or primary water may replace the oil, but these causes of trouble are unpreventable.

Cave-ins, however, can be prevented by using strainers or screens in place of the perforated casing generally used in the fields. It is customary to cut a hole, square or round, and with dimensions anywhere from 1/4-in. diameter to 3/4-in. These large perforations admit a great deal of sand and in consequence cavities form around the casing. Cave-ins may result, due to the cavities, conditions favoring them, and much damage be done to the well. Strainers would do away with cave-ins. These strainers are made by cutting horizontal slots in the casing with the width of the slots slightly smaller than the average diameter of the sand grains. By using either form of strainer a minimum quantity of sand enters the well, with the result that cavities do not form in the oil zone. Were strainers or screening used in the California fields more generally, disastrous cave-ins would soon cease.

Where a neighboring well is at fault, cooperative methods of treatment should be resorted to, unless the neighbor is unwilling to remedy the trouble in his wells. If such is the case, the state inspector should be called in and the repair work done at the expense of the unwilling neighbor.

Protection from Water.—In some of the Californian fields, notably Coalinga and the Sunset-Midway district, water troubles have been actively combated by the operators who have created protective associations.

Every company is asked to furnish logs of its wells. Careful contour maps of the field are made from the logs, and the water and the oil strata are correlated. Armed with this knowledge the operators are better able to proceed intelligently in shutting off water.

Changes in Well Temperatures Warn of Danger from Water.—A very ingenious method is employed by operators in the Baku oil fields of Russia to determine water troubles. In these fields the waters that flood the wells are hot. Every day the temperature of a well is taken. If the temperature increases 3 or 4° it is known that water trouble threatens the well and remedial measures are at once taken.

Mud-Laden Fluid.—Mud-fluid is commonly used in the rotary and circulator systems of drilling, but the application of the mud-laden fluid to conserving oil and gas sands is comparatively recent. The theory of the application is briefly given below. The details of its use is best covered in Bulletin 134 of the United States Bureau of Mines.

The mud-laden fluid is used to shut off gas and water sands by the introduction of a fluid sufficiently heavy to overcome oil or gas pressures that will not be overcome by an ordinary head of water. Also the finely particled mud acts as a medium of plugging off oil and gas sands without letting the water enter the sands as is the case with clear water.

Mud-laden fluid, as defined below, has properties decidedly different from ordinary water or from that of a super- or over-saturated mixture of mud and water. It is a mechanical mixture of mud and water.

Mud-laden fluid consists of finely divided clay or mud held in suspension in water. The mud must be of such consistency that the particles will float in the water and will not settle to the bottom when standing. The clay must be pure and not sandy. The specific gravity of such mud-laden fluid should not be over 1.32. By volume it consists of 15 to 20 per cent. of the mixture, and by weight 30 to 40 per cent. of the mixture.

Pure water may temporarily "drown" or deaden a gas sand, but in time escapes into the sand or is blown out of the hole when the gas pressure is a little above the pressure of the water column especially if its water escapes into the sand. Mud-laden fluid is sufficiently heavy to overcome high gas pressures. A column of mud-laden fluid 1 ft. high with a cross-section of 1 sq. in. and a specific gravity of 1.32 exerts a pressure of 0.573 lbs. per cu. in. as against 0.434 for pure water, or 573 lbs. per 1000 ft. as against 434 lbs. per 1000 for pure water, and has the very great advantage of not escaping into the sands, nor does it pack or settle around the casing in such a way as to "freeze" or bind tight the casing. Casing standing in wells for 5 years has been pulled freely from the mud-laden fluid.

Mud-laden fluid and its use is simply a very efficient method of packing off gas, oil, and water sands, in place of cementing and the older methods.

CHAPTER X

NATURAL GAS

Definition.—Natural gas is any gas formed in nature, as for example, marsh gas, sulphur dioxide, carbon dioxide (the "choke damp" of the mines), sulphuretted hydrogen, and petroleum gas.

However, as generally understood, natural gas is the gas obtained from oil or gas fields, which is burned in our homes, and factories in place of gases manufactured from coal or from petroleum.

Geographic Distribution.—At present the main producing gas areas are in the Kansas, Oklahoma, Louisiana fields, in the Pennsylvania and West Virginia, and in the California fields.

Composition.—Natural gas is composed principally of the hydrocarbons, methane, (CH_4) (commonly called marsh gas), and ethane (C_2H_6).

Two elements, carbon and hydrogen, are the chief constituents of all natural gas.

The analysis of four typical gases are presented below.

TABLE XIV

Sample, where taken	Methane	Ethane	Carbondioxide	Nitrogen	Hydrogen	Other hydrocarbons	Helium	Heat units
	CH_4	C_2H_6	CO_2	N_2	H		He	B.T.U. per cu. ft.
1. Pittsburg, Pa.	92.0	3.0	....	2.0	3	....	....	978
2. Midway, Cal. (Dry)	92.0	.....	3.2	0.3	..	3.2	....	998
3. Hogshooter, Okla. (Dry)	94.2	.....	1.0	4.8	..	....	....	1003
4. Glen Pool, Okla. (Wet)	38.75	61.10	2.2	....	..	....	....	1551
5. Dexter, Kansas	14.85	0.41	....	82.7	..	....	1.84	Non-combustible

Gases 2 and 3 are dry gases. Gas No. 4 is "wet" or casing head gas, which contains petroleum vapors. Gas No. 5 is peculiar in that it contains 82.2 per cent. of Nitrogen; and 1.84 per cent. Helium.

Origin of Natural Gas.—The origin of natural gas is as doubtful as the origin of oil. It may be of organic or inorganic origin, that is, formed by the decomposition of animal or vegetable matter, or it may be the result of the interaction of certain chemicals lying at great depths underground.

Some marsh gas is certainly due to decaying vegetable and animal matter, and it is not improbable that the natural gas from petroleum is also of the same origin.

Methane is the most stable of the hydrocarbons. It is highly probable that the heat breaks up the more complex hydrocarbons to form methane, so that gas is being continually formed in the Earth wherever petroleum is found.

It is not at all improbable that tremendous quantities of gas are formed in the change of lignite to bituminous coal, and from bituminous coals to anthracite.

However, speculations along such lines lead to endless controversy, and for all practical purposes it is sufficient to note the occurrences of natural gas, and its economic importance, leaving speculations as to its origin to the ultra-scientists.

Relation of Gas to Bituminous or Petroliferous Matter.—It is interesting to note that gas occurs in regions where lignitiferous, bituminous, or petroliferous shales, are found. The gas generally occurs above the shales, or in porous sand lenses interbedded in the shales.

The relation of commercial accumulations of natural gas to shales are important, as one would not care to locate a well in regions where shales carrying organic matter are absent.

Some commercial gas had occurred in glacial drifts in Iowa, Illinois, and Kansas. The gas was, in all likelihood, marsh gas, resulting from the decay of vegetation, buried at shallow depths. It may also be possible to utilize the marsh gas formed in the Gulf Coast regions, where the marsh gas, if collected above ground would, in some places, have a distinct commercial value as fuel for houses. Tremendous quantities of decaying vegetation occur along in the Coastal plains, and the utilization of the

marsh gas, given off by that vegetation, is only a question of time.

Stratigraphy.—Natural gas occurs in formations of the most recent, to those of the early Paleozaic, Ordovician and Silurian age. In fact, gas seems to be found wherever decaying vegetation or animal matter has occurred. Commercial accumulations are, however, dependent upon the trapping of the gas. The presence of natural gas in the older beds presupposes earlier vegetable or animal life, unless the gas has migrated from younger beds. The fossil evidence bears out this view.

Commercial Deposits of Natural Gas.—Commercial deposits of natural gas are dependent upon two essential factors:

1. A source of supply for the gas.
2. Proper reservoirs.

The source of supply has been treated under origin, and the reservoirs are the same as under structure in Chapter IV.

Migration.—In some cases the gas has, in all probability, migrated from lower beds to higher, due to unconformities, or to faulting, as shown in Figs. 27 and 28, page 62.

Gas due to its nature, travels wherever an opening is afforded, and only comes to rest where there is a relatively impervious covering to prevent its escape. The covering may be a compact limestone, dense shale, or closely cemented sandstone.

Gas generally occurs with oil, but there are many productive gas sands which do not carry oil. These are called "dry" gas sands, to distinguish them from the gases carrying petroleum vapors.

Gas sands occur above or below oil sands; and we also found districts where no commercial oil sands are obtained.

Gas Pressures.—The pressures of gas vary in different fields, and for different depths of gas sands. There is, however, a remarkably close relation of the gas pressures to the depths of the gas sands, below the surface of the earth. Especially is this true in the Mid-continent-Kansas and Oklahoma oil and gas fields, and in West Virginia.

A well (see Fig. 100) 1000 ft. deep will have a pressure of 400

lbs.; one 1500 ft., 600 lbs.; one 2000 ft., 800 lbs.; or approximately 40 lbs. per 100 ft. A study of a large number of wells shows that the pressure is approximately equivalent to a water column the height of the well.

Allowances must be made for the differences in specific gravities of the water, and the differences in elevations between the water table near the surface and the elevations near the collars of the wells.

A column of fresh water 1 ft. high and 1 in. square exerts a pressure of .434 lbs. per sq. inch. Underground waters in the oil

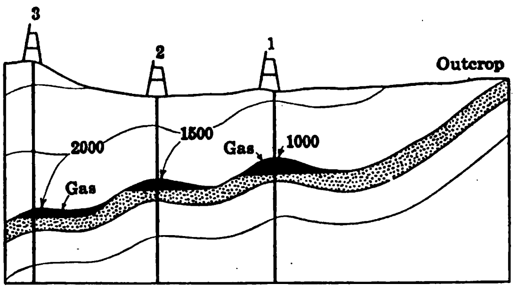


FIG. 100.

and gas fields have specific gravities of 1.0 to 1.3, which would make the water much heavier.

In calculating, however, one can disregard specific gravities, and simply use 0.4 lb. This lower figure allows sufficiently for the loss in theoretical head, due to friction, differences in elevation of the water table, etc.

Allowing for such irregularities the pressures are remarkably consistent; so much so that in regions like Oklahoma and Kansas the gas companies base their estimates of pressures, and also figure the weight of fittings necessary to control the well upon this important relation.

For example, fittings for a well 1000 ft. deep need only to withstand 400 lbs. pressure. A factor of safety of 2 gives 800 lbs.

Such fittings will, however, be unsafe with wells 3000 ft. deep, where there is a pressure of $300 \times 40 = 1200$ lbs. per sq. in.

Fittings capable of resisting only the lower pressure, would be inadequate with the higher one.

There is considerable question as to the cause of the pressure, but there is no doubt that the rule holds with but few exceptions. There is such a close relation between the head of water and the gas pressure that the writer does not feel inclined to disregard the Artesian theory, especially for sands which are exposed to meteoric, or rain and snow water.

The point is raised that if water is holding in the gas, that the water should replace the gas when the gas pressure is weakened. Such, in fact, is generally the case. The gas is withdrawn very rapidly. The water moves more slowly through the pore spaces of the sand, due to minute friction and adhesion, with the result that the gas pressures are reduced for a time. By shutting in a well, however, the gas pressure rises again, showing that hydraulic pressure is back of it.

The writer fully realizes that artesian conditions do not apply at all places. At Fort Smith, Ark., little or no water is found in the gas sand. Pressures of but 145 lbs. to 280 lbs. per sq. in., instead of 400 to 800 lbs., are obtained at depths of 1000 to 2,000 ft. The sands, however, are nearly free of water. (See Carl. D. Smith, Bulletin 541, U. S. G. S.). The writer understands that the synclines carry gas in that field.

Maximum Gas Pressures.—Maximum gas pressures of 1260 lbs. are reported at Midway, Cal., by R. P. McLaughlin, California State Bulletin No. 69, 1915.—1500 to 1700 lbs. are reported in Green County, Pa., by I. C. White, W. Va. Geological Survey, Vol. I*a*.

Cementation as the Cause of Abnormal Rock Pressures.—It may be that where the pores in a reservoir are filled with cementing material that the gas pressures would be much above normal. If the original reservoir were reduced in size, due to cementation, the gas would necessarily lie in a more contracted area and be under higher pressure. This may and probably does account for some abnormal pressures in gas fields.

Gas Volumes.—A few calculations will give some estimate of

the capacity of rocks to hold gas; also the large acreage that must necessarily be drained by gas sands.

Assume as a unit, a sand 1 ft. thick containing 10 per cent. voids, or pore space per cubic foot, and covering 1 acre.

An acre foot of 43,560 ft. of sand under the above conditions contains $43{,}560 \times 0.10 = 4356$ cu. ft. of pore space.

If this space is filled with gas at atmospheric pressure it would contain 4356 cu. ft.

Gas volumes are measured at an average mean atmospheric pressure of 14.4 lbs. per sq. in., and at a pressure of 4 oz. (0.25 lb.) above the mean atmospheric pressure. The pressure approximately corresponds to 14.7 lbs. at 60°F., the pressure at mean sea level. We will accept the 14.7 in our estimates.

Theoretically, the temperature at depth should be taken into account, but in an approximate calculation, like that below, such refinements are of little value.

The number of expansions for 100 lbs. "rock" pressure would be

$$\frac{100 + 14.7}{14.7} = 7.8 \text{ expansions.}$$

The total number per acre foot will be volume of gas $\times$ expansions $= 4356 \times 7.8 = 33{,}976$ cu. ft. per rock pressure of 100 lbs.

At 500 lbs. rock pressure the expansions are 35, and the volume per acre foot $= 4356 \times 35 = 152{,}460$ cu. ft.

For 1000 lbs. pressure the expansions are $\frac{1000+14.7}{14.7} = 69$ instead of 7.8, as one would at first imagine, the added 14.7 lbs. becoming of less consequence the higher the rock pressure becomes. The volume will be $4356 \times 69 = 300{,}582$ per acre ft.

As several wild gas wells have produced from 30, to 70,000,000 cu. ft. per day, and kept it up for months it is a matter of wonder to understand where the gas came from.

The graphic chart (see Fig. 101, after U. S. B. M.) gives some idea of gas volumes in producing fields. This was taken at the famous Caney, Kansas, gas-field, and shows the life of that remarkable field.

The high average volume of 10,694,400 cu. ft. per well, with the rock pressure of 490 lbs. per sq. in., shows that such wells must have drained a very large area, indeed.

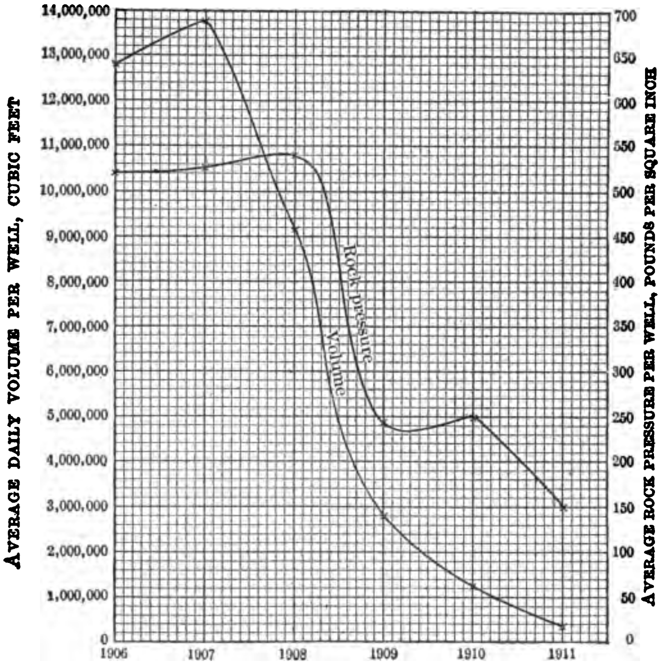


Fig. 101.

Petroleum may act as a solvent for the gas, and hold tremendous volumes in solution. Hydraulic pressures set up by hydrostatic head are certainly not sufficient to liquefy the gas.

Spacing of Gas Wells.—Gas has such mobility that one gas well situated at the top of a dome should in time drain all the gas from the sand.

Good practice, however, allows 100 acres of land per gas well. One well per 40 acres is the minimum of good practice. Allowing one well to drain 100 acres, a well under the conditions given

above, would take care of 152,460,000 cu. ft. for a pressure of 500 lbs. and a sand 10 ft. thick.

Heating Value of Gas.—The value of natural gas in heat is approximately 1000 B.t.u. per cu. ft. The higher the percentage of such hydrocarbon gases, as ethane, etc., the higher the number of heat units. This is clearly shown in the analyses in Table XIV.

Example.—No. 4 carries an unusually high percentage of ethane, which is higher in heat units than methane.

In comparison to coal, petroleum, wood, or producers gas, we have the following table giving some comparative heat equivalents based on B.t.u.'s.

TABLE XV

Fuel	B.t.u.	Equivalent in B.t.u.'s of 1,000,000 cu. ft. gas	Value
Natural gas, per cu. ft.	1,000	1,000,000,000	@ 10c. per 1,000 = $100.00
Oil gas	850	1,176,470	@25c. per 1,000 = $294.00
Producer gas, per cu. ft.	200	5,000,000	@5c. per 1,000 = $250.00
Petroleum 14, B. gravity	18,500	160 bbls.	@$1 per bbl. = $160.00
Coal (bituminous), per lb.	12,500	40 tons.	@$2.50 per ton, 40 tons = $100.00
Wood per lb.	5,000	66.6 cds (1 cd. = 3,000 lbs.	@$3.50 per cord = $198.00

However, B.t.u.'s do not measure the true efficiency of gas. Combustion of gas is greater than the other fuels, so the actual efficiency will be 10 to 20 per cent. greater.

As the combustion of gas is superior to coal, oil or wood, the efficiency of gas is greater than the heat units would indicate.

Casing Head Gasoline.—The development of the casing head gasoline industry has sprung into prominence within the past five years.

It has been found that gas coming directly off petroleum carries hydrocarbon vapors that can be condensed by pressure. These vapors consist of the lighter hydrocarbons that go to make up

naphthas, benzene, and gasoline, having specific gravities of 70° to 100° B.

A rich gas may carry 5 gallons of gasoline per 1000 cu. ft., but 1 gallon per 1000 cu. ft. can be made to pay if a sufficiently large quantity of gas is obtained. The gasoline is first extracted, and the "dry" gas is introduced in the gas line for fuel.

Conclusion.—The geology of natural gas is readily understood. The chances of the occurrences of commercial natural gas is so much greater than other fuels, that the writer has wondered at the relative lack of interest of manufacturers, in the possibilities of employing such a cheap fuel, and also, at the lack of comprehension by gas men, of the value of geology as applied to prospecting for natural gas.

CHAPTER XI

CAUTIONS

In the foregoing chapters the elementary principles of oil-field geology have been outlined. A few further points may be of interest.

Prejudice against Geologists.—In many places much prejudice exists among drillers and operators against geologists. There is absolutely no need for such feeling. Both classes of men have their distinct work to do. A driller's work supplements that of the geologist, who blazes the way into new districts and points out the best places to drill. Instead of conflict, there should be mutual respect and cooperation.

Just because most geologists are men of technical training and education is no reason for prejudice on the part of the operator or driller. The geologist in his line is as practical as the driller, and uses perfectly open and legitimate methods of work, and his working methods and instruments are as well standardized as are the tools and methods of the driller.

Again men who are ignorant of geologists' methods of work and knowing of their success, will overrate the geologist and his liability to make mistakes, and also in some cases put the geologist on a pedestal. When he fails, as is often the case, they lose faith in a geologist's work. Minimizing risks is the best work of a geologist, and if he reduces chances on wildcats from one in ten to six in ten, then he has accomplished good work. A geologist's function, however, is far more comprehensive than locating "wildcats" as one will clearly understand if he has followed the earlier chapters closely.

Exactness.—Many people think that a geologist's work is exact. Such is not the case, by any means. Where under-

ground conditions are to be considered, exactness ceases. One cannot definitely say that a certain condition, such as a fault or a fold, persists underground. Many times it may not do so. One must qualify such statements by saying in all probability such a condition may exist underground, or the evidence leads us to believe such a condition to exist. Depths are predicted within certain limits, not down to the last foot.

The work of the geologist is not exact nor can it be so. There are districts in which exposures are so scarce that one cannot obtain a sufficient amount of data, on which to base any positive conclusions. In such cases one must leave the structure unmapped and uncertain. In all mapping and study of the structure, the percentage of errors varies due to the following factors:

I. Engineering errors:
- (*a*) Instrumental errors.
- (*b*) Errors in observation.
- (*c*) Errors in reducing from large natural scale to small map scale.
- (*d*) Errors due to drill logs.

II. Geological errors:
- (*a*) Errors due to the thickening or thinning of beds.
- (*b*) Errors due to unseen faulting, unconformities, lensing, etc.

The first set of errors are mechanical and personal; the second set due to natural factors.

Instrumental errors can be avoided by careful work. Where an aneroid barometer is employed, the per cent. of accuracy will not be as great as with a spirit level or plane table and alidade system. Errors in observation are due to the personal equation and are only overcome by careful checking. Errors in reducing from natural scale to map scale are not of such importance if the earlier work has been carefully done.

Errors due to geological conditions such as the thickening or thinning of beds and to unconformities, faults, etc., cannot be predicted. Such errors are due to natural conditions that occur at depth and cannot be foreseen by the geologist or engineer.

Errors in well logs are the results of: 1. Improper classification of strata. 2. Inaccurate measurements. 3. Careless log making.

Often drillers and geologists fail to classify beds properly. A bed that may in reality be 200 ft. lower is sometimes called a certain key bed—say the Oswego limestone when it may be an entirely different bed.

The measurements vary with the methods used. The usual way is to measure off units on the sand line or steel drilling cable, wrap a string around the place of measurement, and then to count the number of strings or units that go into the hole when the sand line or the cable is unwound. The unit taken with the sand line is the length of line from the top of the sand line reel to the top of the casing, approximately 170 ft. for the 82-ft. derrick. This distance is sometimes measured with a 5-ft. stick, though a steel tape is generally employed.

If the drill cable is used for measurements, the length of line from the top of the bullwheels to the top of the casing is used, and the measurements of the unit is obtained by the steel tape or 5-ft. stick. Obviously when measuring with a 5-ft. stick—slips occur, and measurements a foot short or long per unit may be obtained. This error when multiplied by ten may mean an error of 10 or even 20 ft. in deep holes.

If the measurements are carefully made by such methods the results may be correct within a "screw" of 5 ft. Closer estimates are useless as the driller tells the change in his formation by the "feel" of his tools, the sound, etc., and he may drill several feet into a stratum without knowing it.

Total depths are accurately obtained by measuring with a steel line. Where the casing measurements are taken, it is easy to check the thickness of formations; also the total depth is accurately obtained in this way.

Careless log making is responsible for many errors. The driller may encounter a certain bed at a specific depth. Instead of marking the depth at once on his log book the driller may carry it in his head, and if busy, forget the exact figures, with the result that he later approximates the depth and is off sometimes 20

ft. or more. Such errors can only be eliminated by carefulness on the part of the driller.

However, even eliminating all instrumental and personal errors there are still the uncertain geologic factors that may upset the most careful surface measurements. Nicety and exactness is desirable, but there is a limit to refinement of work beyond which it is a waste of time to go.

Salting Samples.—"Salting" is sometimes resorted to as in mining. A few examples of such methods will prove instructive. The writer has in mind one company that was accused of employing a "salting" method. The true solution in this case, however, was far different, and the "salting" was unconsciously done by the examiner himself. The consulting engineer who made the examination used what is popularly called a "bucket gauge." This method of gauging consists in holding a 5-gallon bucket at the mouth of the lead-line and noting the time required to fill the same. A number of important factors must be taken into account in figuring production by this method. Oil shrinks from 20 to 60 per cent. due to the escape of enclosed gas. It is customary to allow the oil to settle 24 hours and then measure the shrinkage. Also to have an accurate gauge the same rate of pumping speed must be maintained. Water and sand are also present in many cases. Where from 10 to 15 or even 50 per cent. of water may occur, precautions must be taken to provide against mistakes in not testing for same. The consulting man in the case under consideration was ignorant of these elementary principles, and reported upon production as he found it. As a result his report showed a production 100 per cent. greater than the actual production. The purchasers complained that they had been cheated, yet their expert sent in a true report according to his light on the subject. No one at all familiar with oil-field methods would have considered such a gauge as accurate. The best method is to obtain reports for runs made to pipe-line companies, and then check up the same by extended tests at the wells, using both bucket and tank gauges. The only accurate gauge method is an actual tank gauge showing

a run over a period of a week or more, with the examiner or his representative on the ground at all hours. Wells vary greatly in their production from hour to hour, but a 24-hour gauge will be fairly constant provided the pumping speed is the same.

Prospect holes are sometimes salted simply by filling with oil and then bailing out the same for prospective investors. Such a method is crude but has been successful during "boom" times.

A very interesting and yet amusing incident occurred to a friend of the writer who undertook an examination in Louisiana. An oil spring was reported to this friend and he made a trip to the region in which the find was reported. There was undoubtedly oil in the spring as a thick scum of heavy oil floated on the surface of the water and more bubbled up from below. The consulting man studied the spring which lay at the bottom of a gentle slope. The district was one that showed little or no evidence of structural deformation and according to all reports on the district, oil should not have been found if structure counted at all. But there was the oil spring to confute all theories. The engineer, however, felt that something was wrong. As the region was a wild one and the natives a hard lot, the owner of the spring in particular having the reputation of being a "killer," the young geologist said little and sparred for time. That night he stole from bed, located a pick and shovel, and started for the spring, some half mile from his host's house. On reaching the spring, queer to relate, no oil bubbled up. Getting down on his hands and knees he probed around the bottom of the spring; his hand encountered a small pipe which gave a clue to the solution of the mystery. There was but one place the oil could come from, and that was near the top of a small knoll close by. The engineer finally located a spot that showed signs of having been recently dug up, and soon uncovered a large barrel containing crude petroleum, a "plant" that might have made the owner's fortune. The engineer covered up all traces of his visit and returned to bed and next morning took the first stage out of the region and did not return to buy up the promising oil land.

Occasionally samples of oil are switched and fraud thus per-

petrated on the examining man. Careful attention to samples will do away with such fraud, however.

Self Deception.—Self deception as regards oil properties is not unusual. Thus in drilling for oil some of the lubricating oils for the machinery have been known to leak into the drill hole, causing a temporary excitement, as the drillers thought the traces of oil presaged a good supply below and boomed the district on such showings. If oil has been found in quantity it nearly always shows strongly in the material dumped from the bailer, and a study of the sand pile will generally give a good clue as to whether or not oil has been found. However, the only true test lies in a careful examination and actual gauging of the well. An actual pumping test tells the tale and no engineer should be content without making such a test where it is possible to do so.

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